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HAZE CLIMATE OF THE UNITED STATES

by

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1. INTRODUCTION

This is a climatic atlas of the haze over the contiguous United States for the time period 1948 to 1983. It covers the spatial and temporal pattern of atmospheric haziness in a climatic sense: in terms of synoptic distribution and secular trends. It also contains a rough attribution of haze between man-induced and natural causes. The attribution of the man-made haze to specific sources is beyond the scope of this atlas.

The spatial and temporal distribution as well as the man-made causes of atmospheric haze have received considerable attention from researchers on this continent since the late 1970's. (e.g. Ferman 1981; Leaderer et al., 1979; Miller et al., 1972; Munn 1973; Robinson et al., 1982; Sloane 1982; Sloane (in press); Trijonis 1982; Weiss et al., 1977; Wolff et al., 1982). Much of the recent literature deals with physical-chemical properties of haze, with the aim of understanding its sources and formation mechanisms. Intermittently, various investigators have reported haze maps covering parts of North America. The first and most valuable set of such haze maps for the U.S. were published by Eldridge, 1966.

In a sense, this is a progress report of the continuing haze research at CAPITA that was initiated in 1976 (Husar et al., 1976; Husar et al., 1979; Husar et al., 1981; Husar et al., 1982; Husar et al., 1984). Since 1982, through a Cooperative Agreement EPA has supported the maintenance and updating of a visibility data base. This report is a product of that data acquisition, maintenance and analysis. The availability of such large scale data base on a timely basis permits the monitoring of the regional shifts in atmospheric haziness. Undoubtedly, such data can be of benefit for the monitoring of the nation's atmospheric environment, effectiveness of existing control strategies, and the development of future ones.

2. VISIBILITY DATA BASE

The sources and the gross features of visibility data have been described in the past by almost all investigators dealing with the subject. The following discussion will be limited to those items that are directly relevant to the climatic maps and trend graphs in this atlas.

The trend data base consists of 137 stations for which computerized data exists since the 1948-1952 period. They are depicted in Figure 1. The spatial coverage of stations is particularly dense in the Northeast. Regrettably, data for North and South Dakota were not available. The temporal coverage for most stations started in 1948, although some stations only have computerized data since 1952. The main data base of 3-hourly weather observations resides on over 50 magnetic tapes. For purposes of spatial-temporal trend analysis raw visibility observations were summarized as monthly averages of noontime light extinction coefficient (24 / visual range, miles). For each month and station, three different extinction coefficients were calculated: the first set includes all visibility data regardless of weather and pollutant conditions (BX); the second group (FX) is composed of extinction coefficients excluding precipitation (rain and snow) and fog events; the third group (RX) excludes precipitation, fog, and also an RH correction was performed to compensate for water and vapor effects. This latter parameter is closely related to the dry fine particle aerosol mass concentration. The functional form of this correction factor is shown in Figure 2. The correction is RX = BX / f(RH), which primarily serves to reduce the apparent extinction coefficient at relative humidities above 80%.

A problem with visual range measurements is that there is always a furthest marker beyond which the visual range is not resolved. This translates to a lower threshold value for the computed extinction coefficient. For this reason, the mean is inappropriately biased upward, and more reliable, nonparametric statistical indices are more useful. In our analysis, the 25th, 50th, 75th and 90th percentiles of each of the

Figure 1. Surface synoptic locations

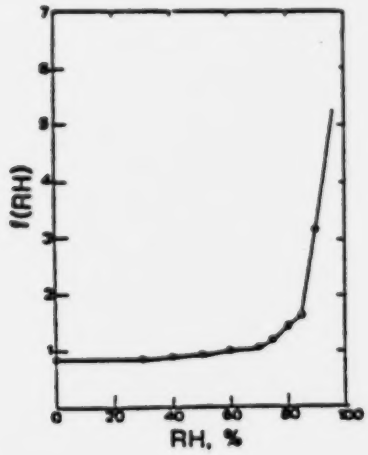

Figure 2. RH Correction function for bext

three extinction coefficients are calculated monthly for each station. Other statistical quantities such as means and standard deviations can be computed from the percentiles once it is established which percentile is valid, i.e. above the threshold.

The utility of the computed percentile values is demonstrated in Figure 3. For Sioux City, IA, the trend graph shows that from 1948 to 1968, the threshold extinction coefficient (FX) was at 16, and then dropped to 8×10^{-6} m^{-1}. Since the 50th percentile was near the high initial threshold, this median would indicate a drop in the later periods; the mean would show a strong decrease in the late 1970's. The 90th percentile, however, appears to be a robust reliable measure which is above the threshold influence; it indicates a clear increase in extinction over the entire period. Thus, depending on whether one follows the 50th or 90th percentiles, one would arrive at opposite conclusions about the trend.

The excellent spatial and temporal coverage of the visibility data base can be utilized only after careful site by site scrutiny for anomalous behavior such as this. The following results were compiled after extensive examination of each site's percentile trends. The advantageous feature of systematic threshold offset is that the properly presented data can identify its limitations and provide remedies for them.

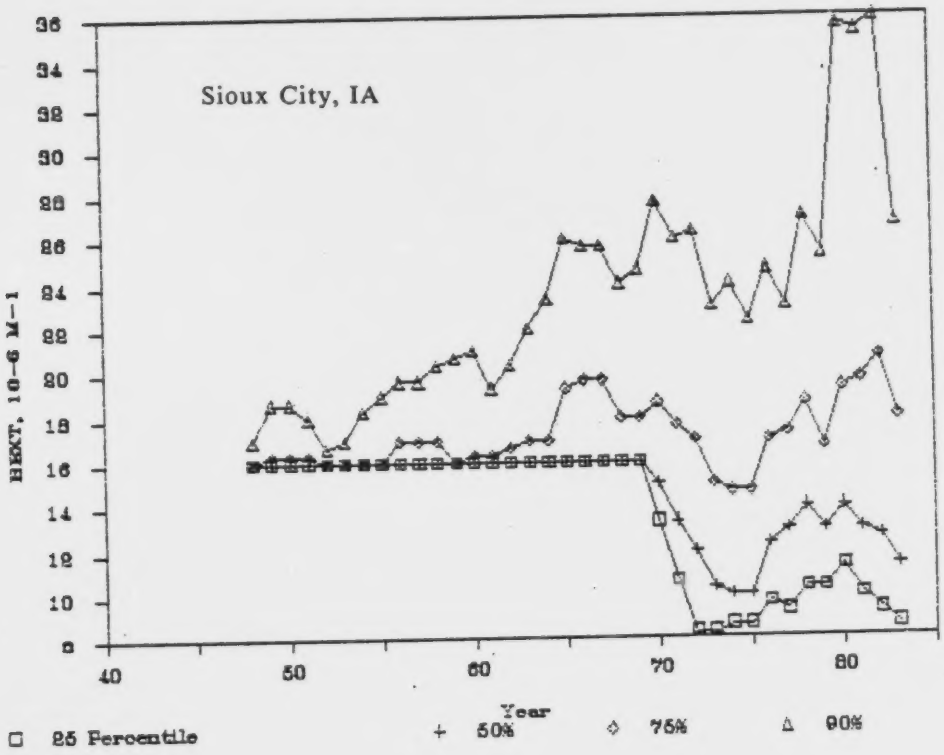

Figure 3. Trends of percentiles at Sioux City, IA

3. CLIMATIC MAPS OF THE U.S. HAZE

The essence and summary of the present haze atlas is given in Figure 4, 5 and 6. The specific parameter that is plotted for both maps is the 75th percentile. While this is unconventional, it constitutes the safest approach in that it did not require any extrapolations or other adjustments to the data. More conventional statistical measures can be estimated as follows: from previous research, e.g. Husar et al., 1979, the extinction coefficient is roughly lognormally distributed with typical logarithmic standard deviation of 2.5. For such a distribution, the 50th percentile is 0.5 times the 75th percentile, and the mean is 0.76 times the 75th percentile. Thus, if one is to convert the maps, the scales of the intervals must be multiplied by the appropriate fractions. We recognize that even if the haze is lognormally distributed everywhere, its log standard deviation will tend to vary geographically and seasonally. The available data suggest, however, that its range is confined to 1.6 to 3.4.

The climatic maps for the two parameters are grouped, 16 maps each, representing four time periods and four seasons. The time periods are selected to center around 1950, 1960, 1970 and 1980, while the four quarters are January - March, April - June, July - September, and October - December.

Quarter 1, All data (BX)

Figure 4 shows the 75th percentile coefficients for all data regardless of weather. The first quarter haziness, shown in the top row of maps, demonstrates that the worst visibility is in the area surrounding the Great Lakes, while the best visibility is in Arizona and New Mexico. The poor visibility region around the Great Lakes has changed somewhat in the 1948-1983 period: a decline in the Northeastern states (New York) and an increase in the upper midwest. This latter upward trend in the Dakotas may in fact be spurious, since there are no actual stations in those two states. However, the increase in MN and WI is real, since it is based on three stations. There is also

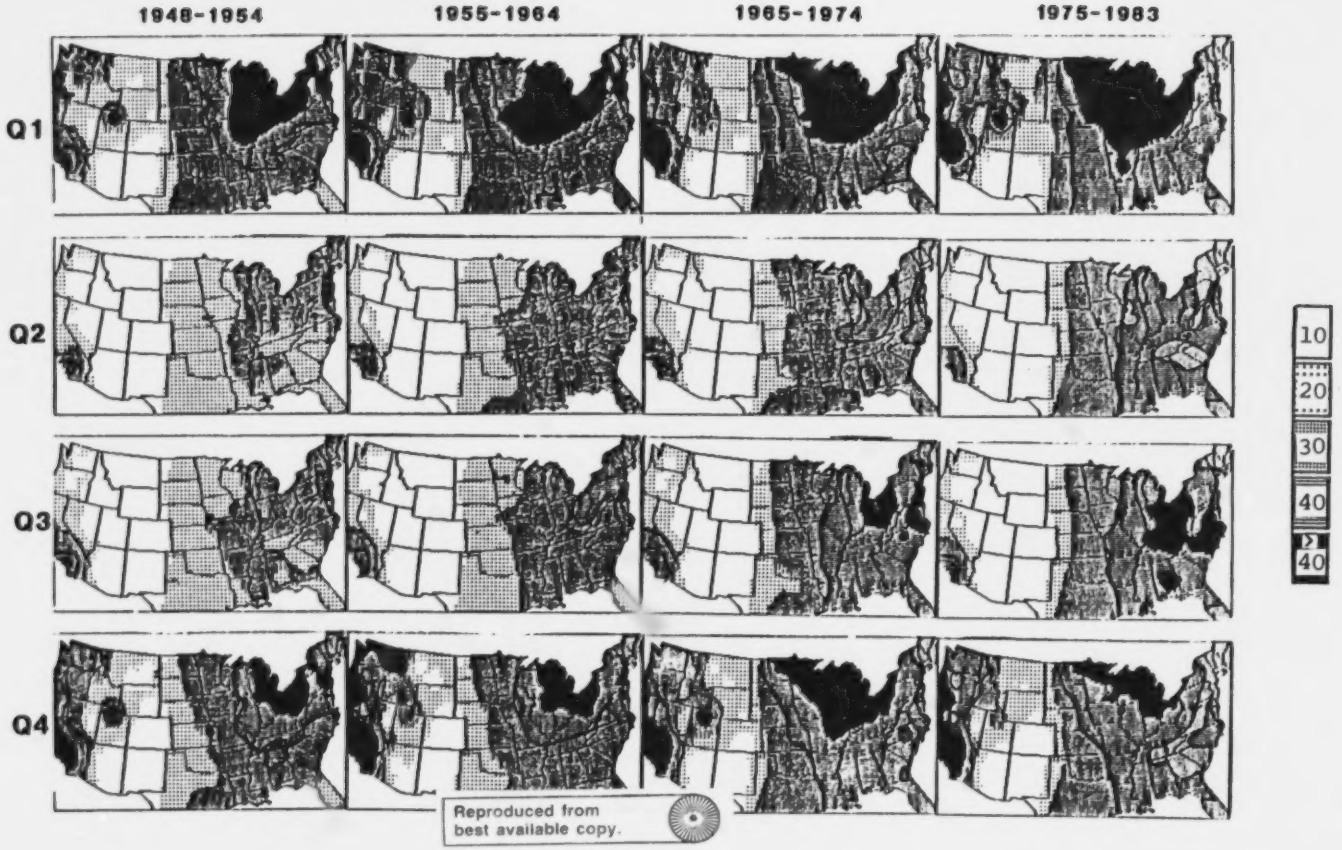

Figure 4 Atlas of BX light extinction coefficient

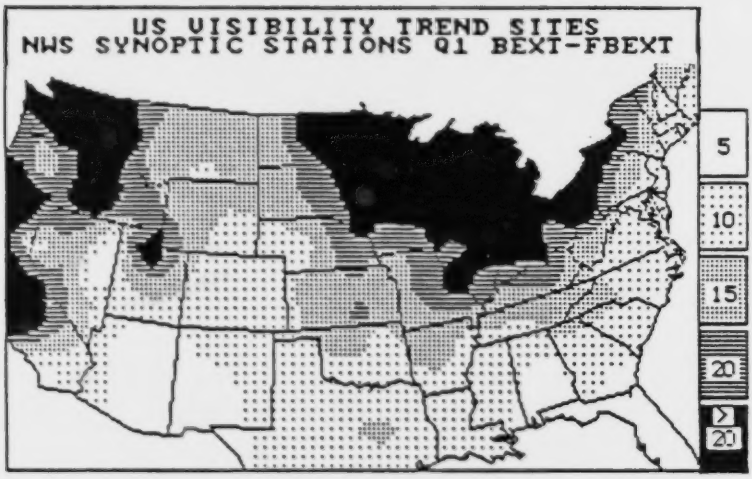

Figure 5. Atlas of winter extinction due to weather

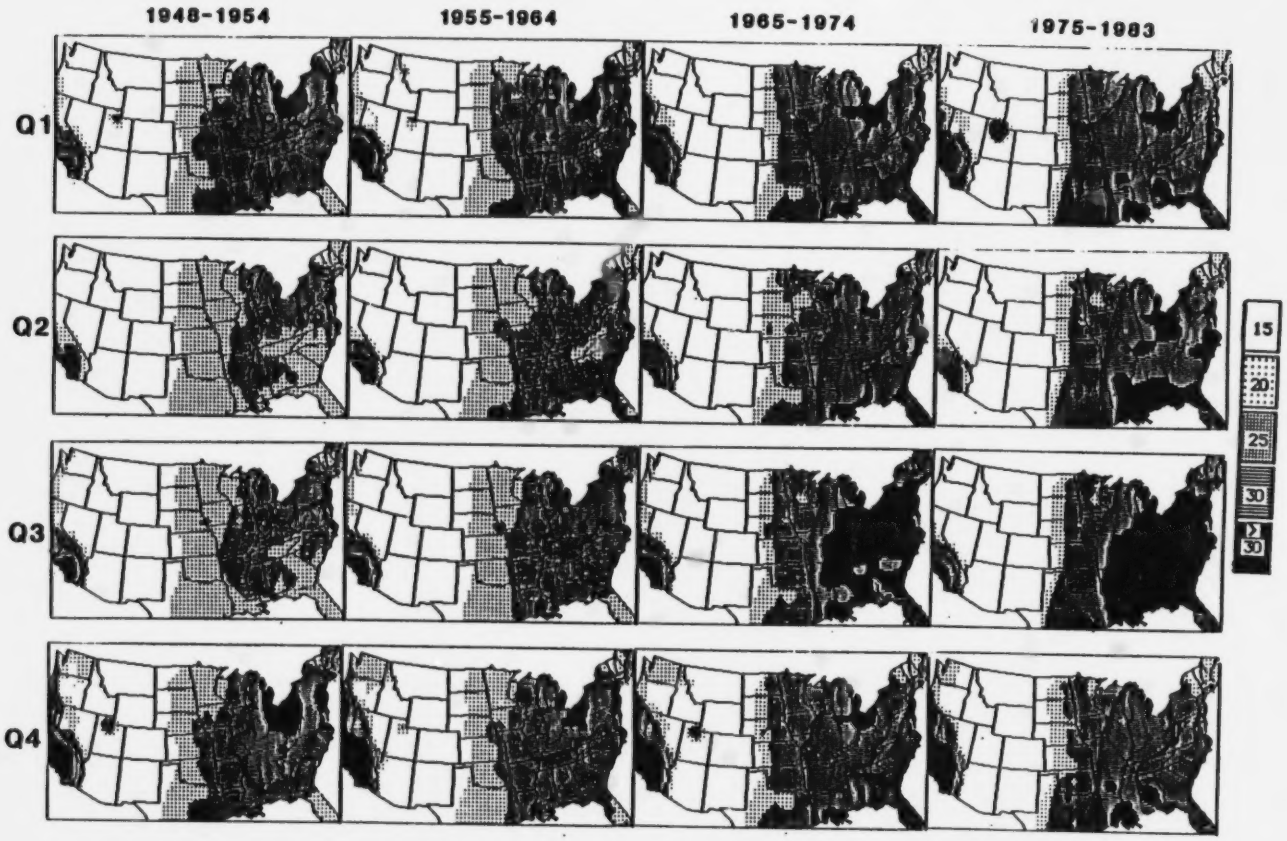

Figure 6. Atlas of RX light extinction coefficient

evidence of declining overall winter visibility in the Gulf states. The winter visibility in the Rocky mountain states is rather varied: nest in the southern states AZ and NM, and declines with increasing latitude. Superimposed on this latitudinal trend are two hot spots, Salt Lake City, UT and Missoula, MT. These two sites stand out particularly in the 1955-1964 period. Undoubtedly, these are localized hot spots of winter haze caused by processes within their local environment. It is likely that if more stations were available, additional poor visibility hot spots would show up. The visibility over the California-Oregon coast has evidently declined in the 1948-83 period, but much of the increase has happened in the 1950's and little since then.

Quarter 2. All data

In the second quarter (April-June) a significant increase is exhibited over the United States east of the Rockies. The states west of the Rockies have not changed significantly. Around 1950, the low visibility region was confined to the Ohio and Mississippi valleys. By the 1980's, much of the eastern U.S. was covered with springtime haze.

Quarter 3. All data

The most significant changes are noted for the third quarter, July-September. Evidently the visibility in Southern California has improved while the visibility in the southeastern states south of the Ohio River has declined substantially.

Quarter 4. All data

The fourth quarter haziness exhibits similar pattern to the first quarter, both qualitatively and quantitatively, the outstanding feature being the poor visibility over the west coast states and those surrounding the Great Lakes. It is also interesting to note the decline of haziness in the Great Lakes region since the 1970's.

Undoubtedly, the extinction coefficient shown in Figure 4 is strongly influenced by the occurrence of precipitation and fog. The role of these natural meteorological events is particularly important for quarters 1 and 4. This is shown quantitatively in

Figure 5, which represents the excess extinction coefficient due to fog and precipitation for the first quarters of 1975-1983. It is evident that well over half of the extinction coefficient is due to precipitation and fog in the Great Lakes and western states. On the other hand, the wintertime extinction coefficient is not significantly influenced by precipitation and fog over the Gulf states. An interesting further noteworthy feature of Figure 5 is the hot spot around Salt Lake City that shows local phenomena classified as fog and precipitation to be significant. In addition to the removal of fog and precipitation events, additional correction is required for the noontime relative humidity effect. The results of the thus corrected maps are presented in the next section.

RH corrected data, excluding precipitation and fog.

The relative humidity corrected maps shown in Figure 6 are indicative of the dry fine particle concentration over the nation. Hence it represents a "pollution index" for visual air quality. The winter season "dry" haziness is most pronounced over the Great Lakes states, California and the Gulf states. Pennsylvania and New York show declines of dry haze from the 1950's to the 1980's. Ohio has not changed significantly. The California stations, particularly in the south coast basin, show increased winter dry haze, particularly from 1940 to 1950. The most significant wintertime increase is noted for the Gulf states, Louisiana, Alabama, Mississippi, and Georgia.

Second and third quarter haziness shows an increase over all states east of the Rocky Mountains. The increase is most pronounced for the Gulf states, and least over the northeast and California.

Quarter four closely resembles the spatial and temporal trends over the first quarter. Again, notable exceptions are the improved late fall visibility in the Ohio region.

4. TRENDS OF HAZE AT SELECTED SITES

The secular midday summertime trends of RH BEXT percentiles for all stations are presented in the Appendix. In this section, a few sites representative of regional behavior are discussed briefly.In all figures, the lines represent the 25th percentiles (squares), 50th (plus sign), 75th (diamonds) and 90th percentile (triangles).

The haziness at Long Beach, CA, was among the worst in the nation in the 1950's and 1960's, with median visibility of about 6-8 miles (Figure 7). Beginning in the early 1970's, the visibility has shown a clear and consistent trend to improved visibility.

The trends at Phoenix, AZ, since 1948 are given in Figure 8. Generally low levels of extinction have been present throughout the period, with clear indications of reduced haziness since about 1974.

Figure 9 shows the record of haziness at Des Moines, IA. Here there is no evident trend in the median, particularly since much of the trend is obscured by the threshold problem up to 1970. The higher percentiles, however, appear to exhibit an upward trend over the entire period.

Madison, WI trends also indicate a consistent secular increase in haziness (Figure 10), although the 25th and 50th percentile information is lost until 1980. A sharp increase in haziness is evident about 1978, likely due to local influences.

The trends in Figure 11 indicate that New Orleans, LA, has experienced increased haziness since the late 1950's. A rather sharp jump in the lower percentiles occurred about 1968.

The trend at Jackson, MS, (Figure 12) indicate a rapid rise in haze at the lower percentiles, including the median, beginning about 1976. The median extinction coefficient rose by 50% in the past decade.

At Columbus, OH, Figure 13 indicates that the gradual increase in haziness from about 1960 reversed itself, indicating little change over the past decade in summertime haziness there.

Our earlier studies, (e.g. Husar et al., 1979) found evidence of remarkably rapid increase in average haziness at Charlotte, NC from the mid 1960's to 1974. The current analysis of percentiles (Figure 14) shows that the strong increases have halted about 1974, with no evidence of further trend over the past decade.

In New York City, visual range observations at Laguardia Airport show a flat secular trend, with some improvement in visibility in the upper percentiles since the mid 1960's (Figure 15). Nearby sites, e.g. Newark, NJ, are similar. Evidently the haze in the industrialized northeast has not worsened.

Finally, the Burlington, VT, site may be regarded as a remote receptor of regional haze. As seen in Figure 16, the median extinction coefficient has changed very little over the last thirty years, while substantial swings have occurred at upper percentiles. Where such a receptor is periodically hit with heavily polluted air masses, the highest percentiles serve as an index of the aerosol pollution contributed by upwind sources. Here it appears that the higher percentiles increased during the 1960's decade, but have declined since about 1970.

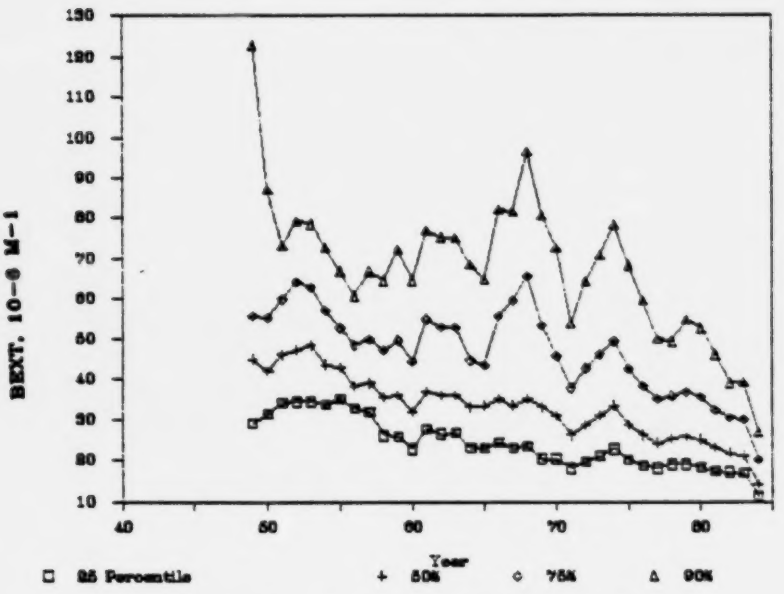

Figure 7 Trend of haziness, Long Beach, CA.

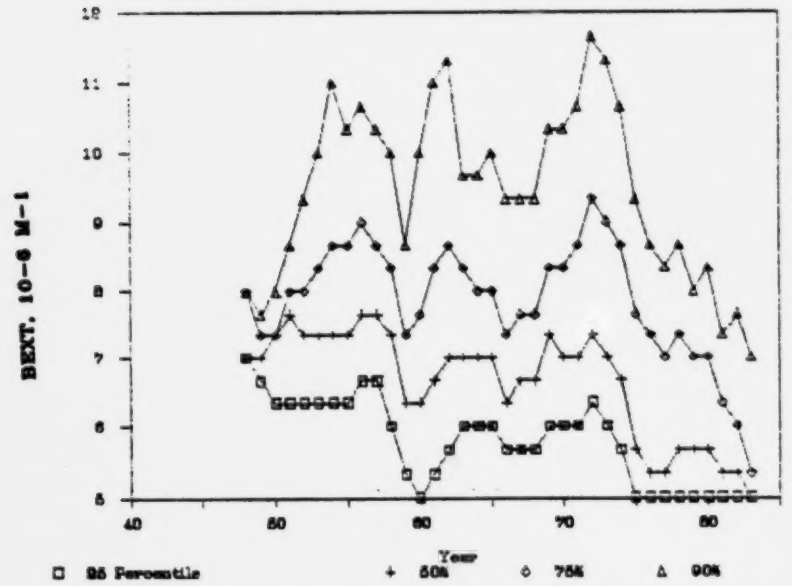

Figure 8 Trend of haziness, Phoenix,AZ.

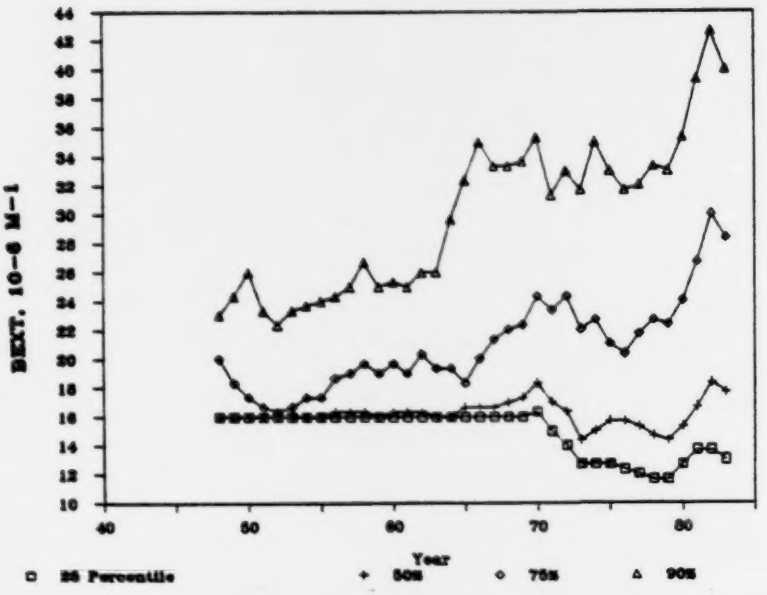

Figure 9. Trend of haziness, Des Moines, IA.

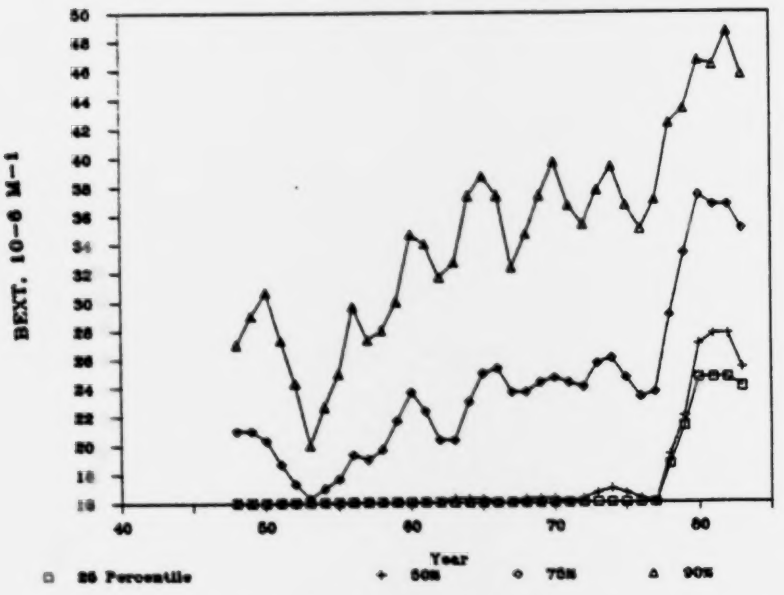

Figure 10. Trend of haziness, Madison, WI.

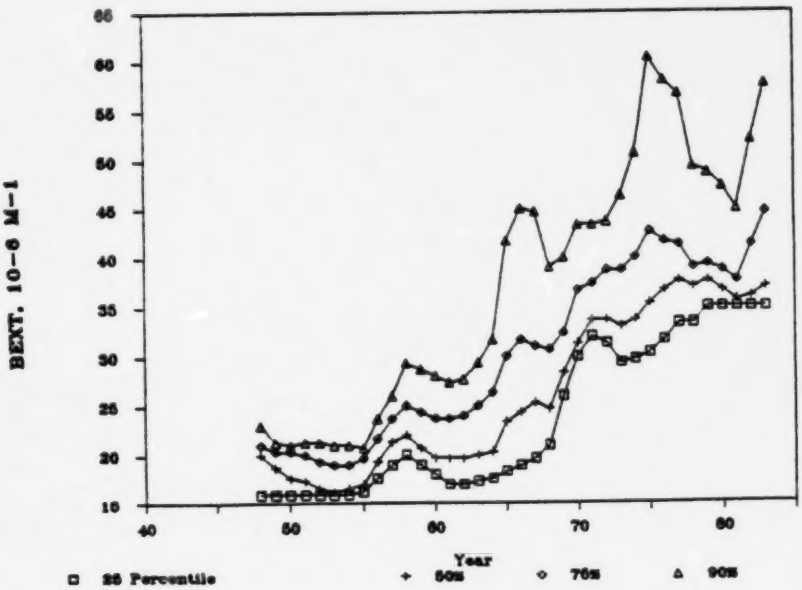

Figure 11. Trend of haziness, New Orleans, LA.

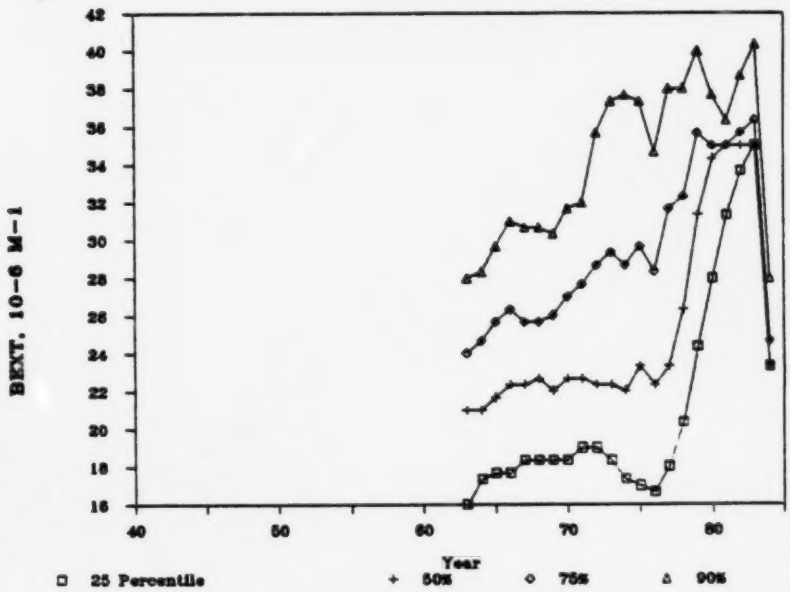

Figure 12. Trend of haziness, Jackson, MS.

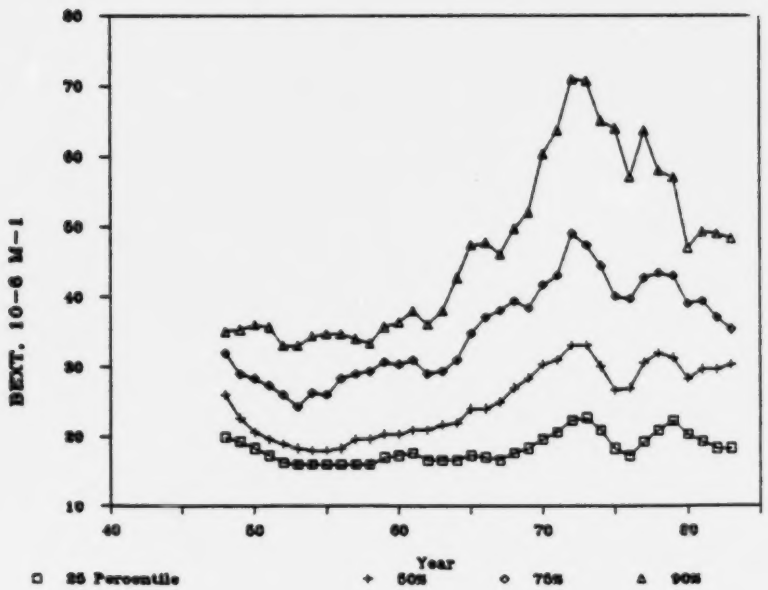

Figure 13. Trend of haziness, Columbus, OH.

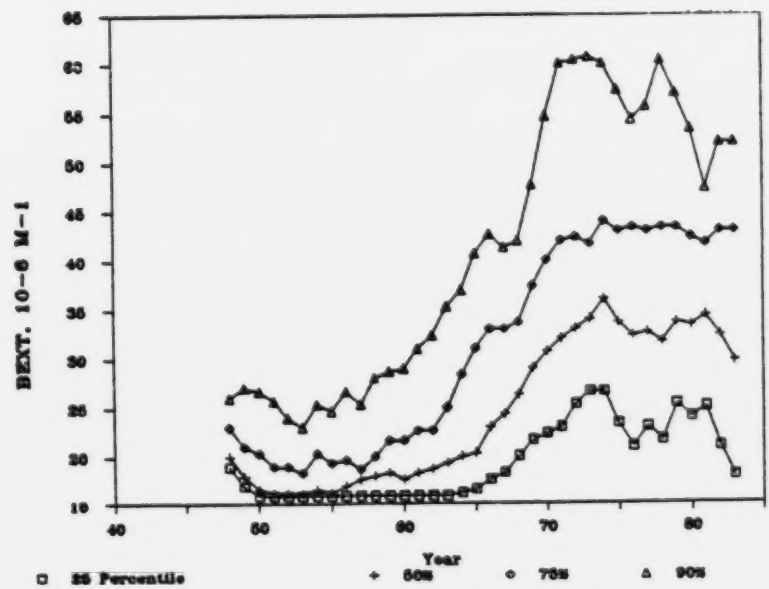

Figure 14. Trend of haziness, Charlotte, NC.

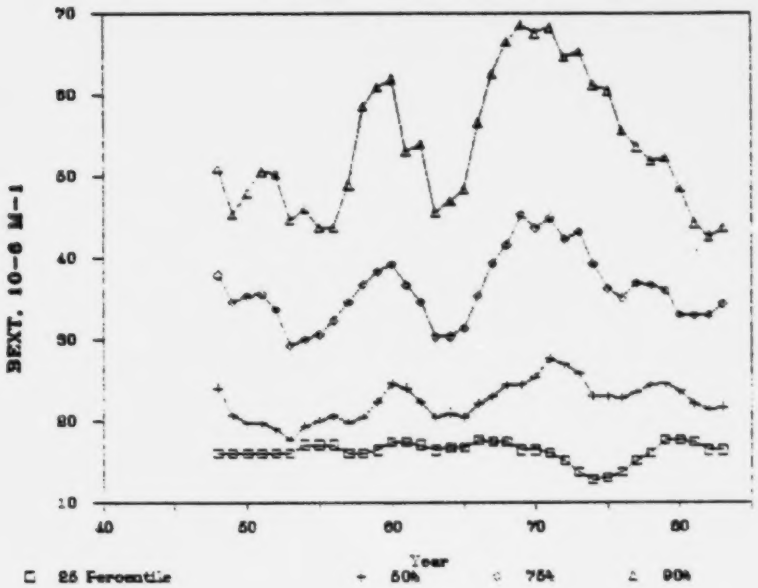

Figure 15. Trend of haziness, New York, NY.

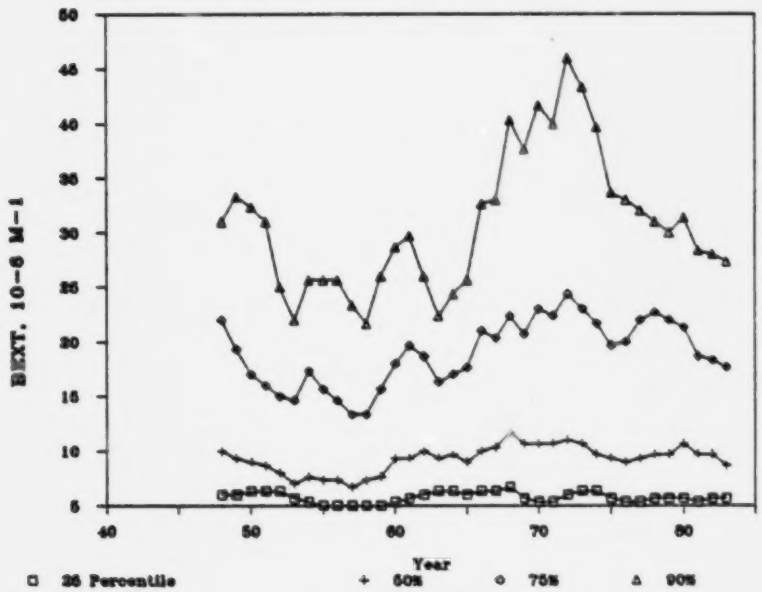

Figure 16. Trend of haziness, Burlington, VT.

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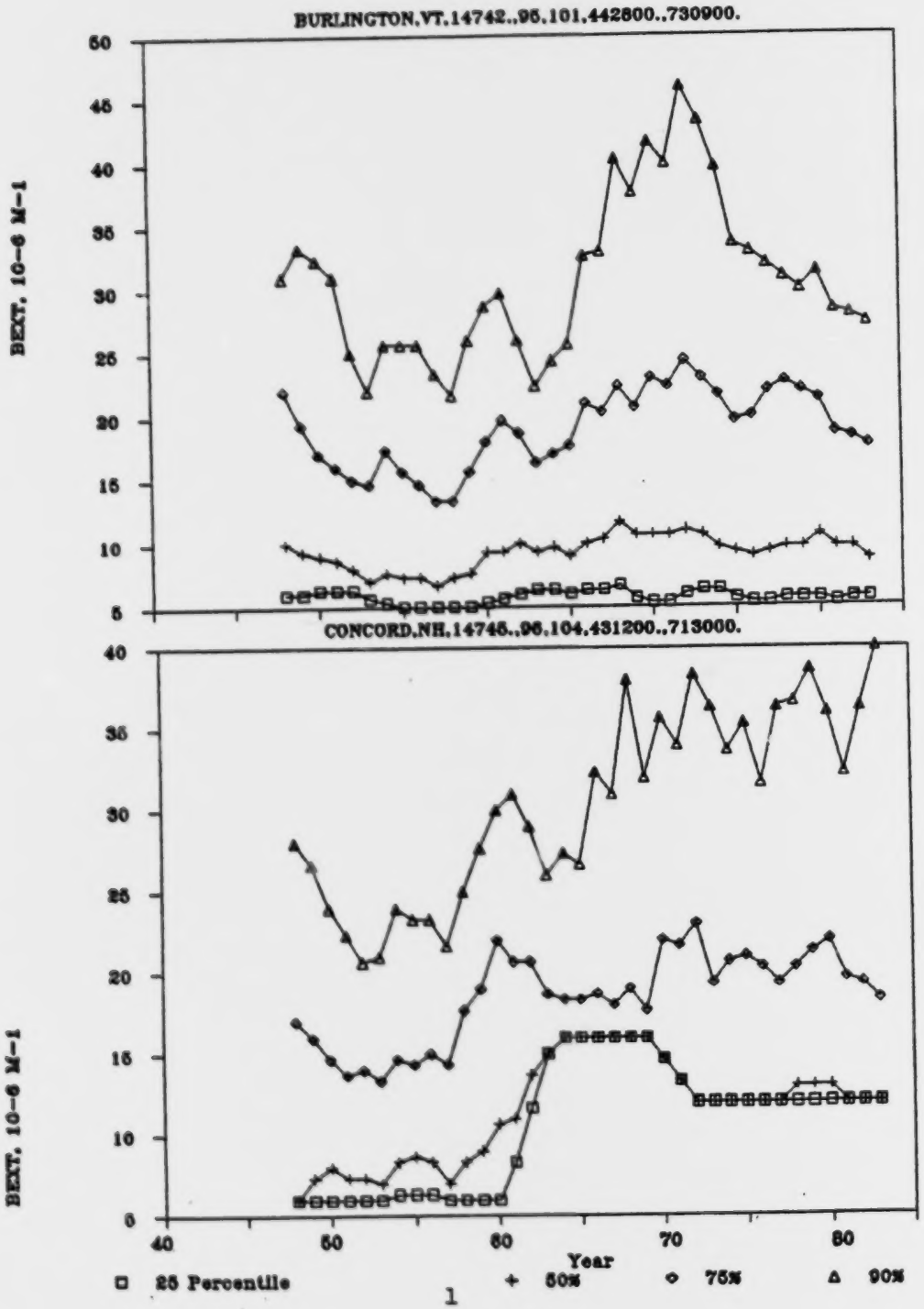
APPENDIX: HAZE TREND AT ALL SITES

The following graphs present the entire set of trend graphs for the 137 site network of visual range observations. Each site indicates summertime midday distribution function parameters for individual seasons at the 25th, 50th, 75th and 90th percentiles.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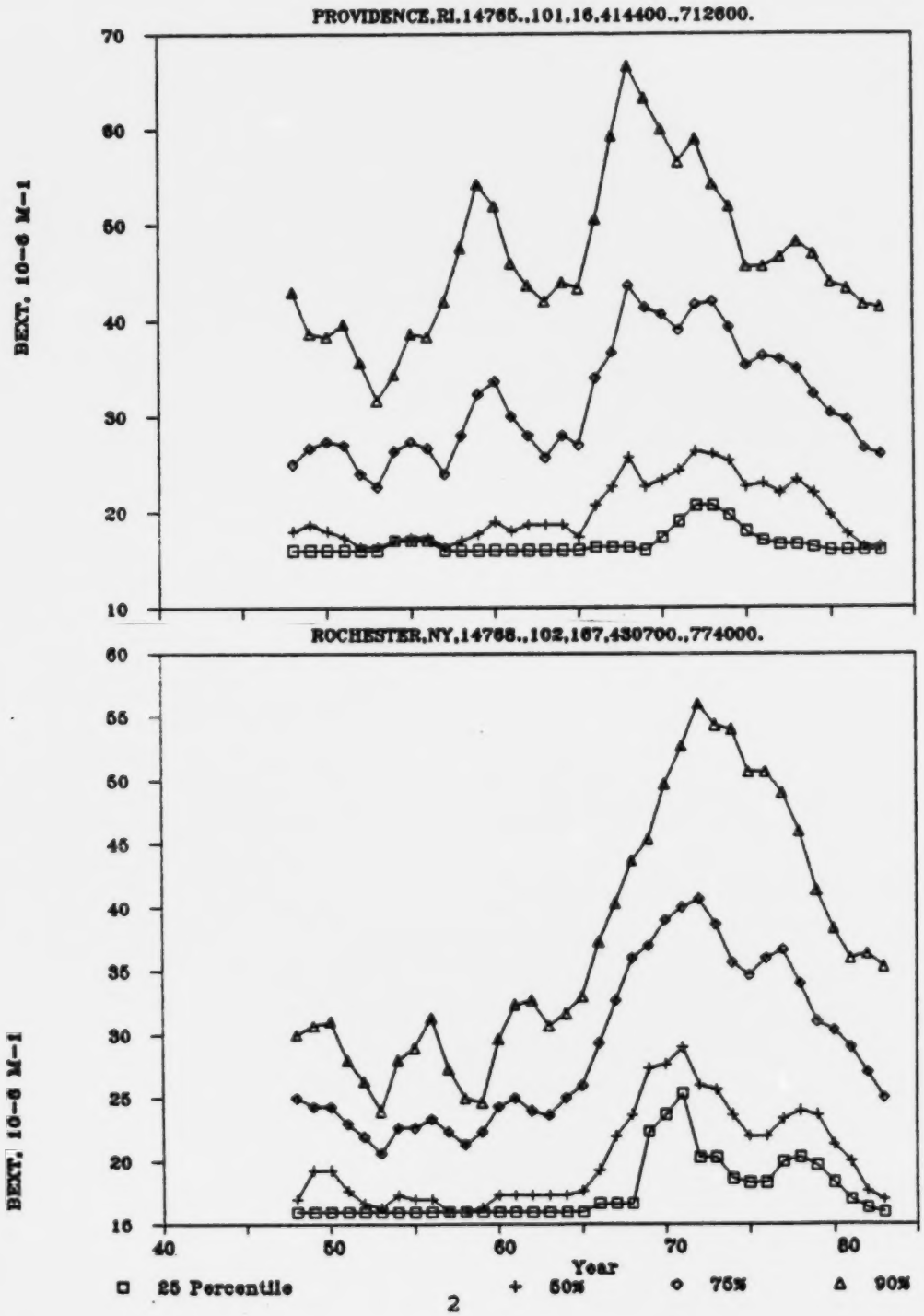
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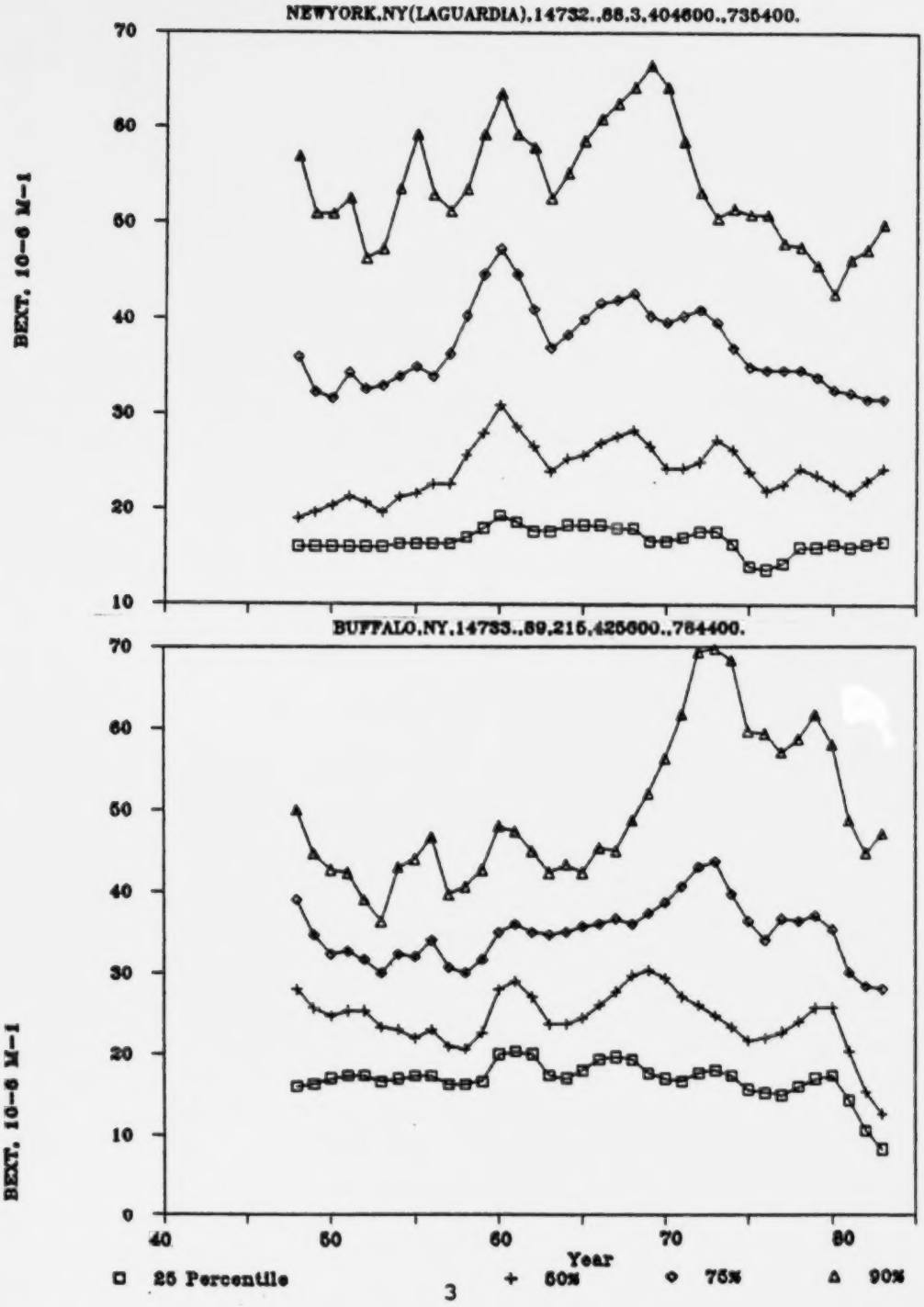
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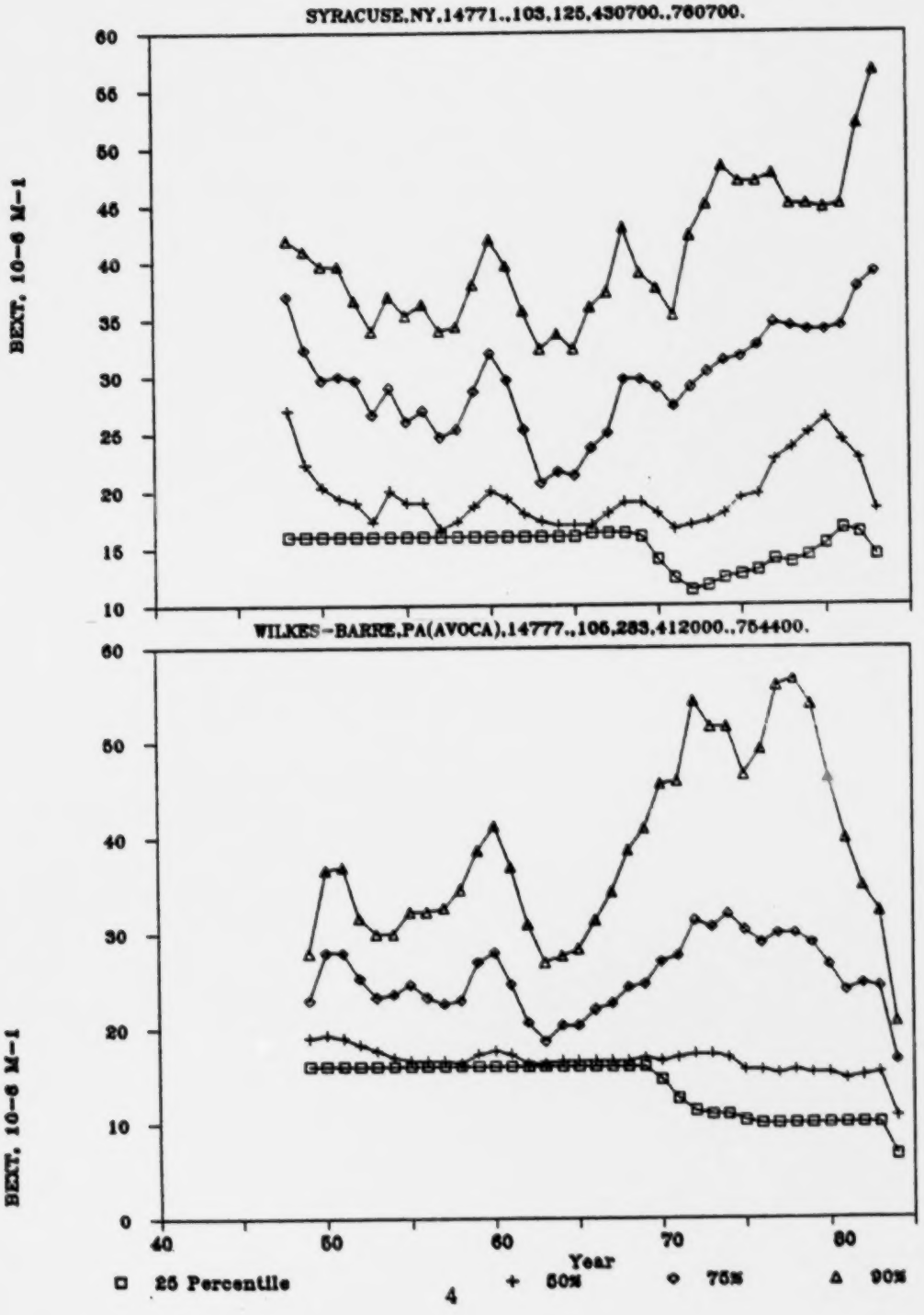
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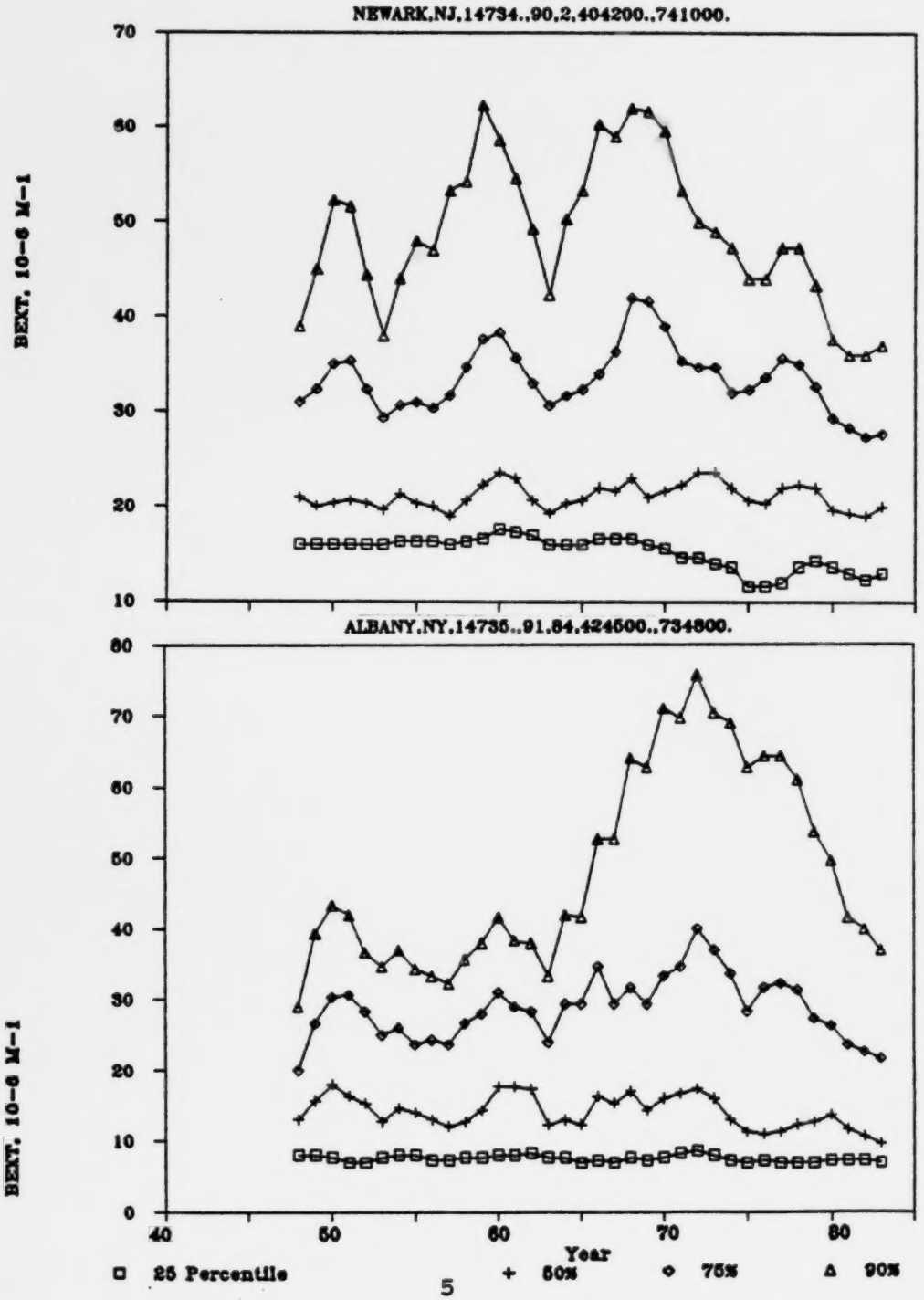
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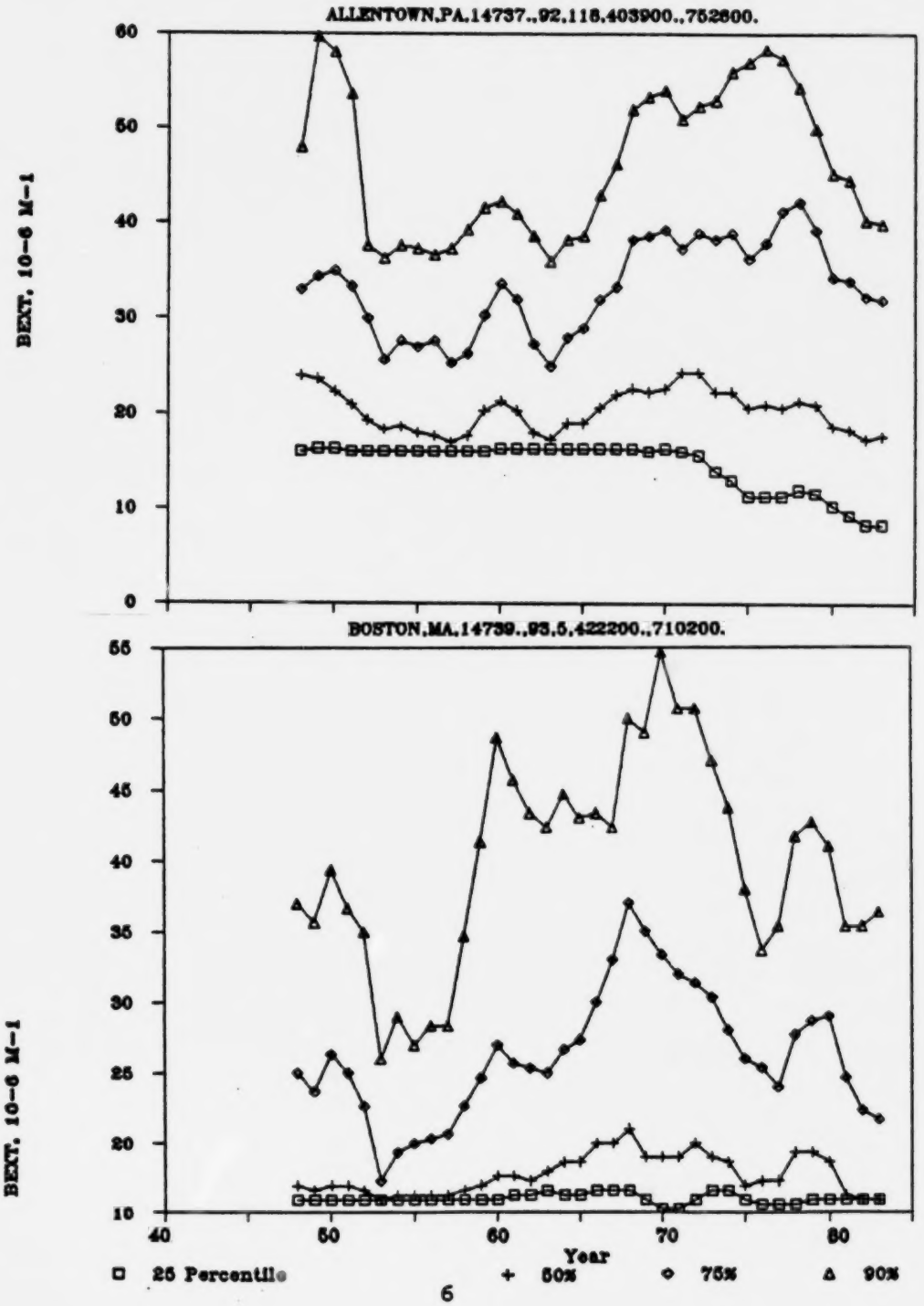
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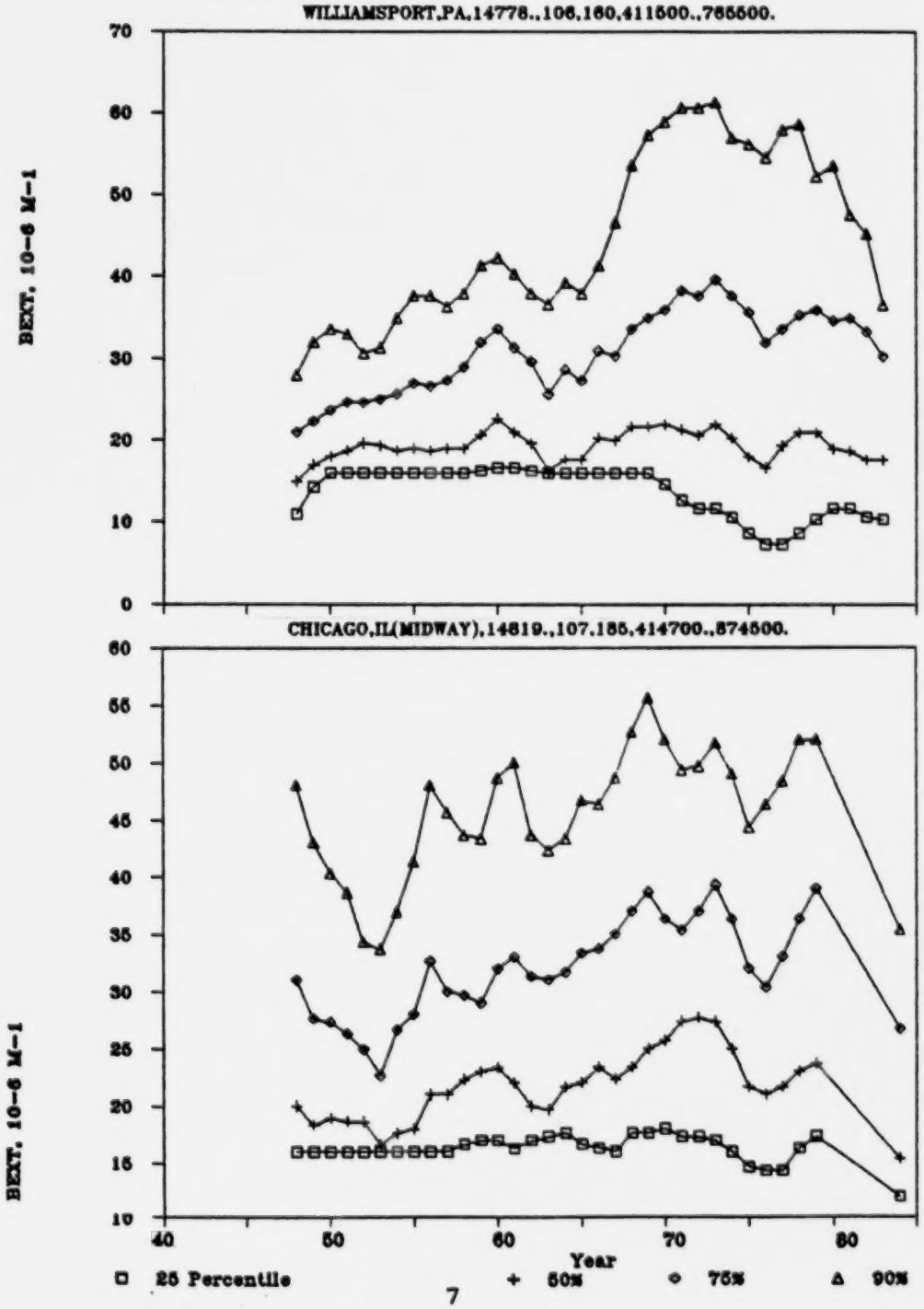
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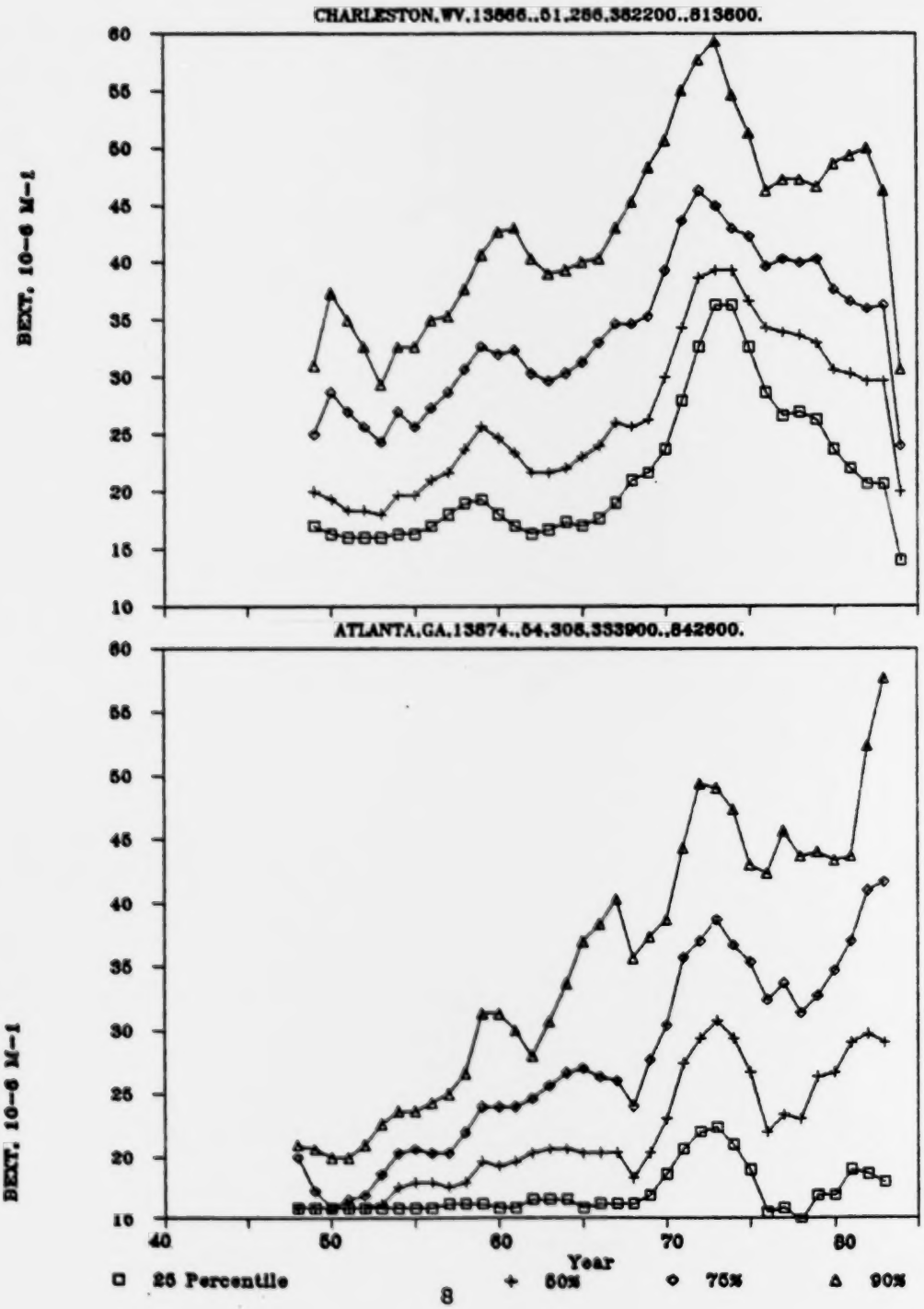
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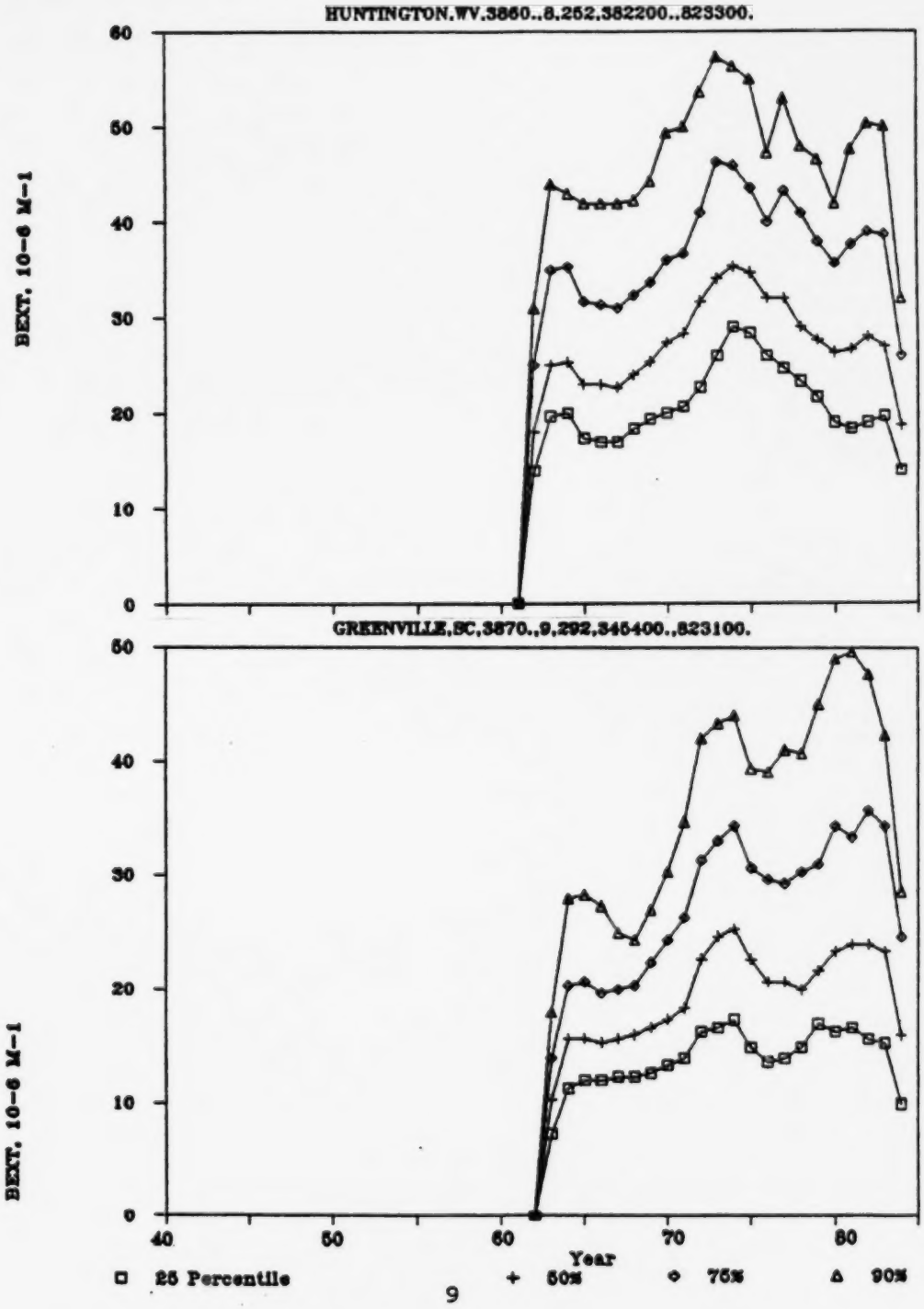
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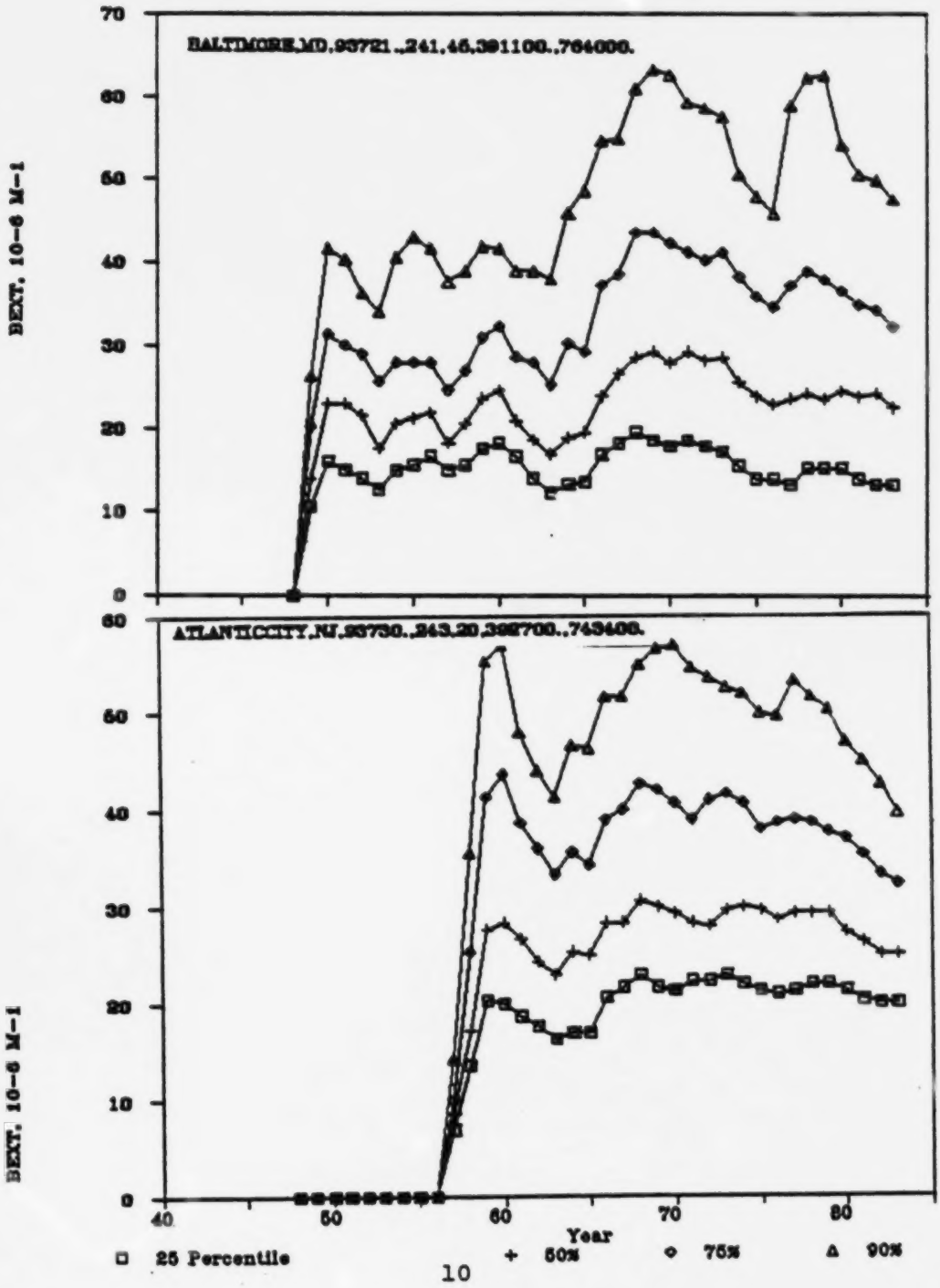
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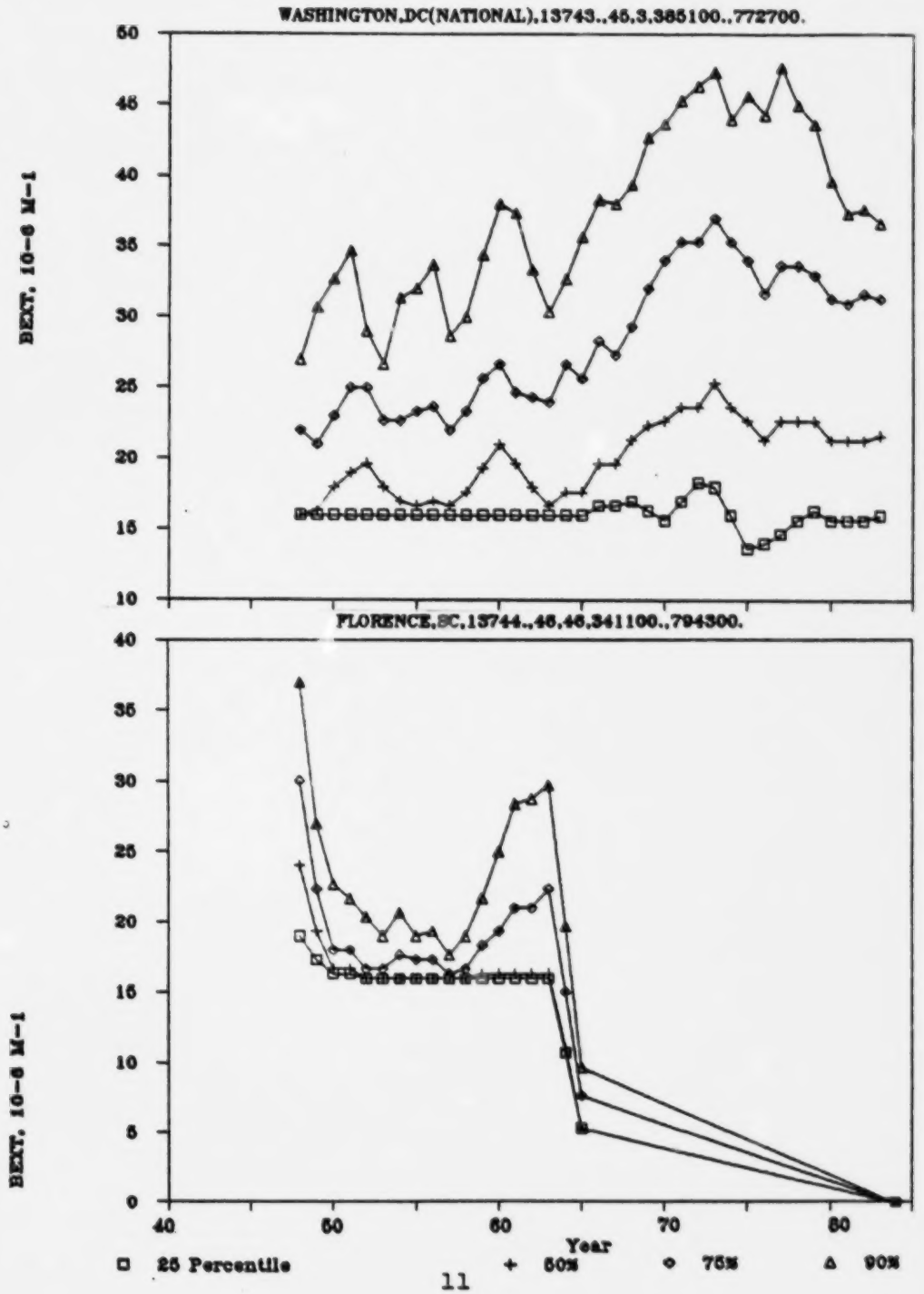
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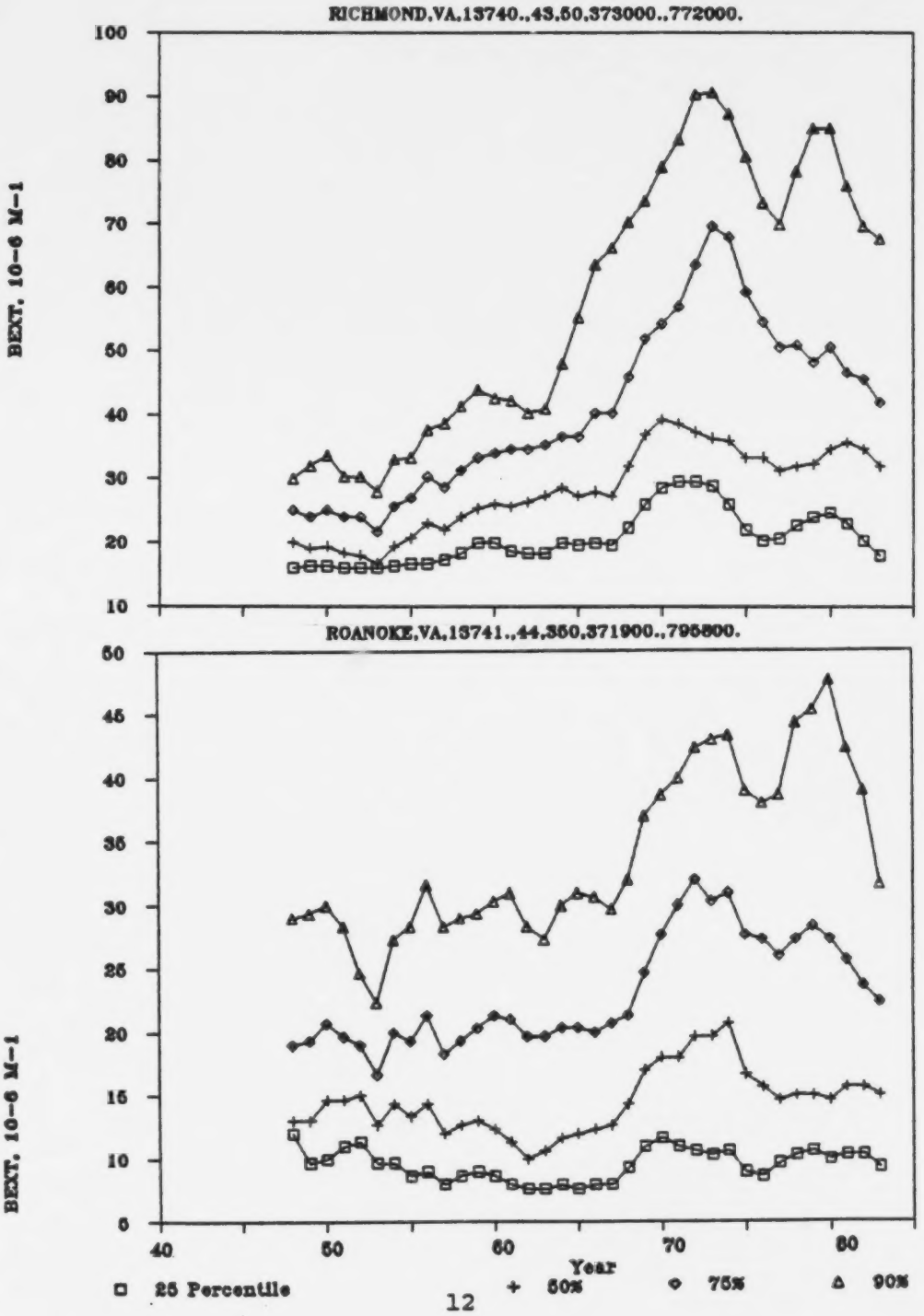
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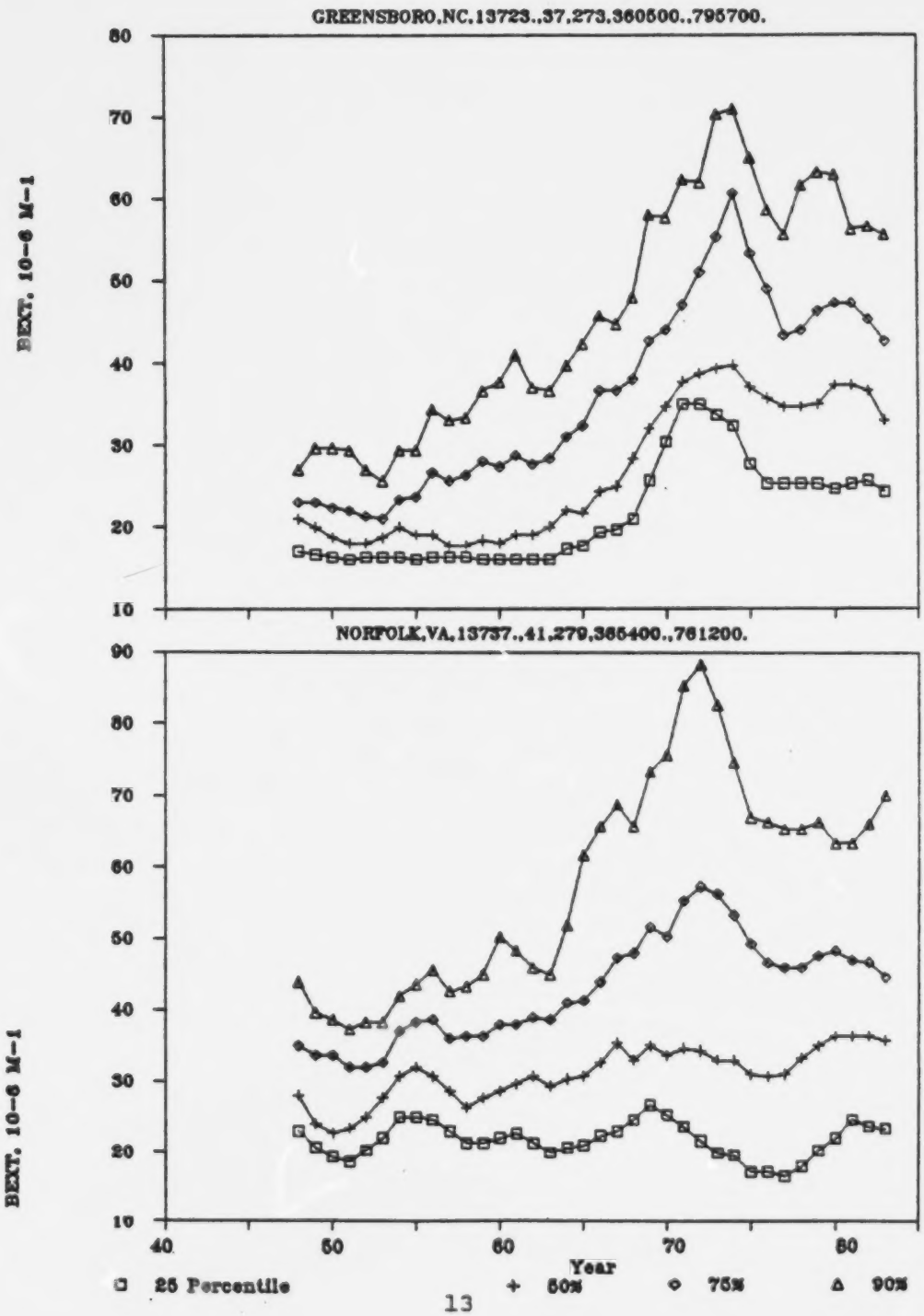
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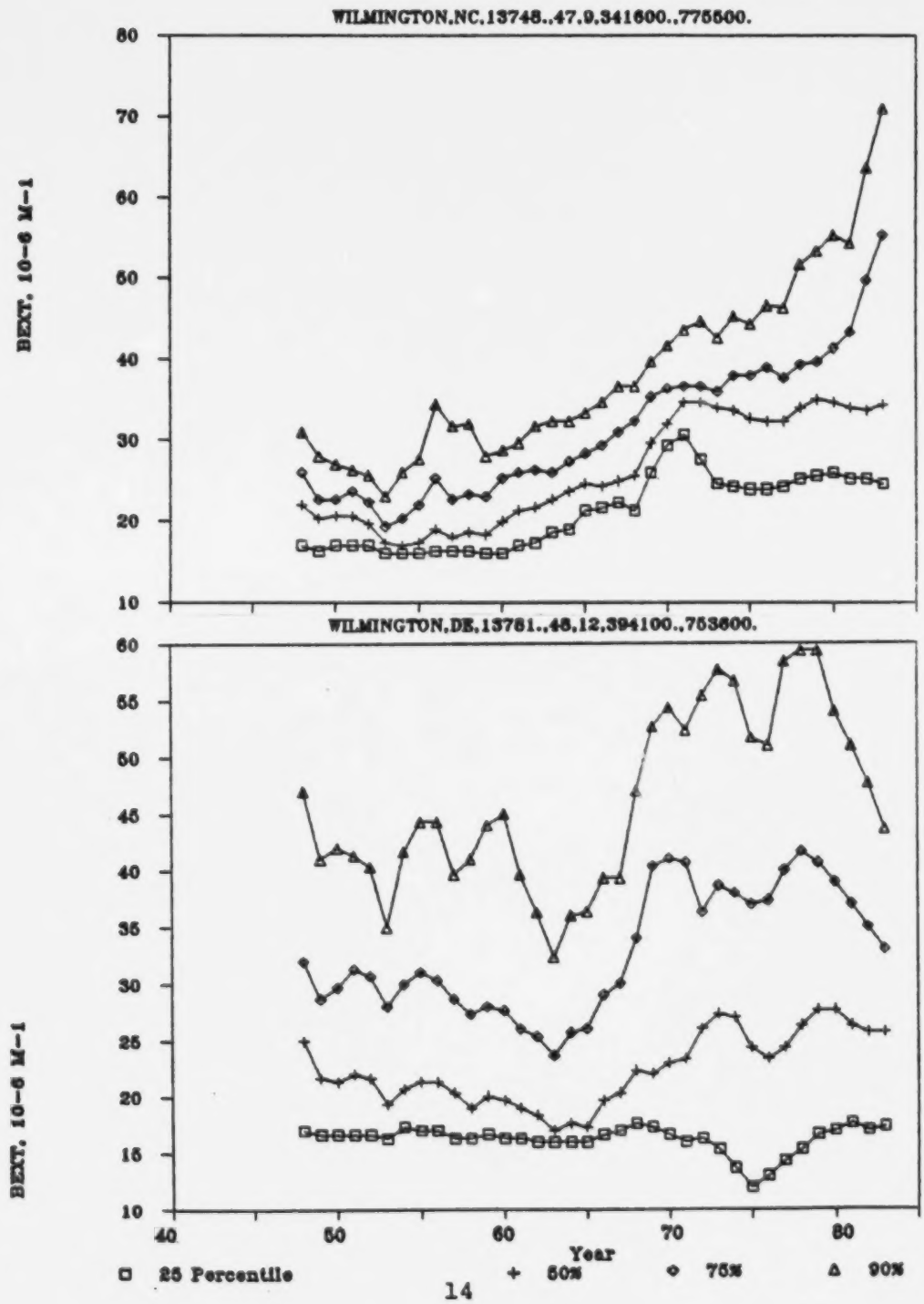
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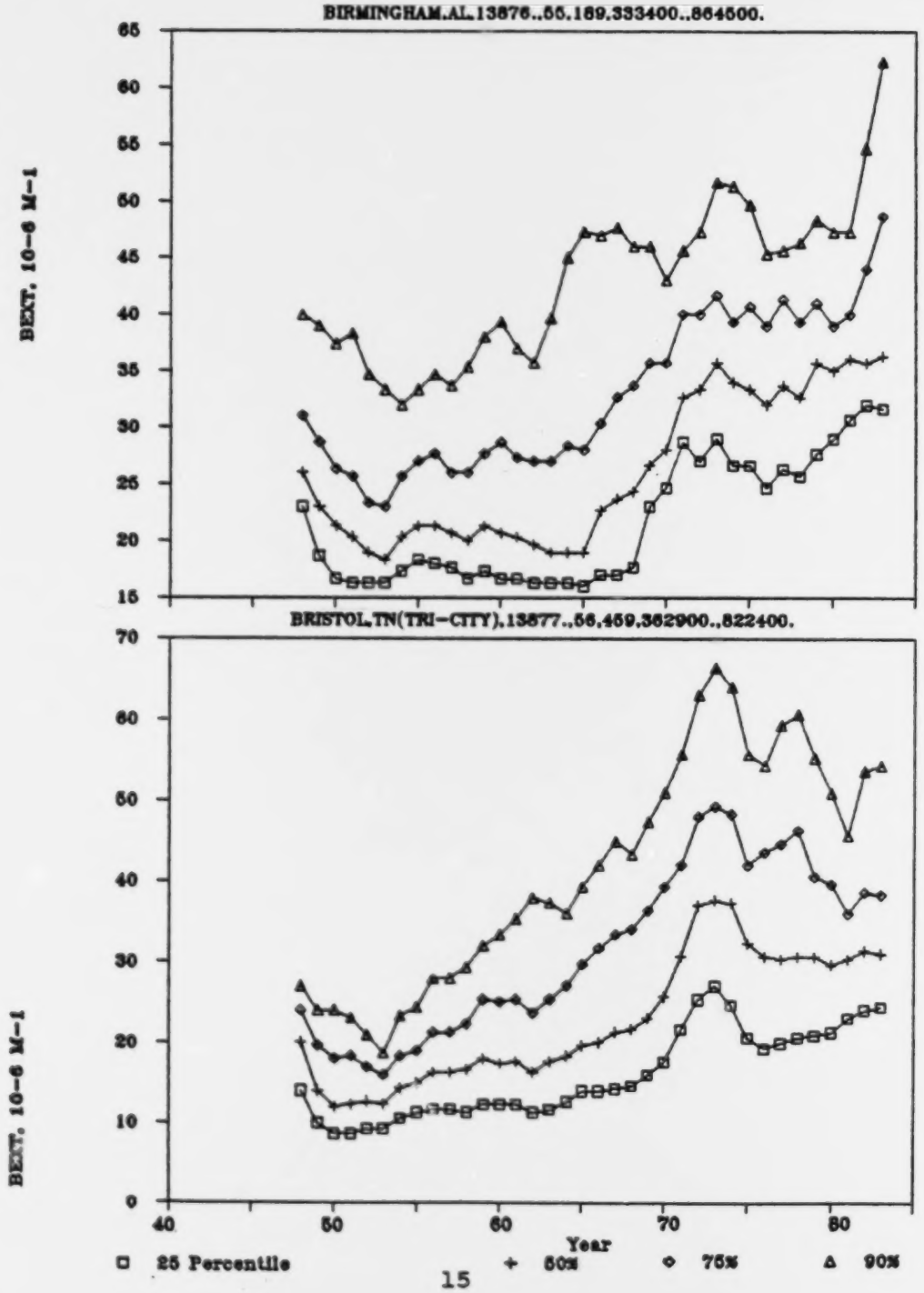
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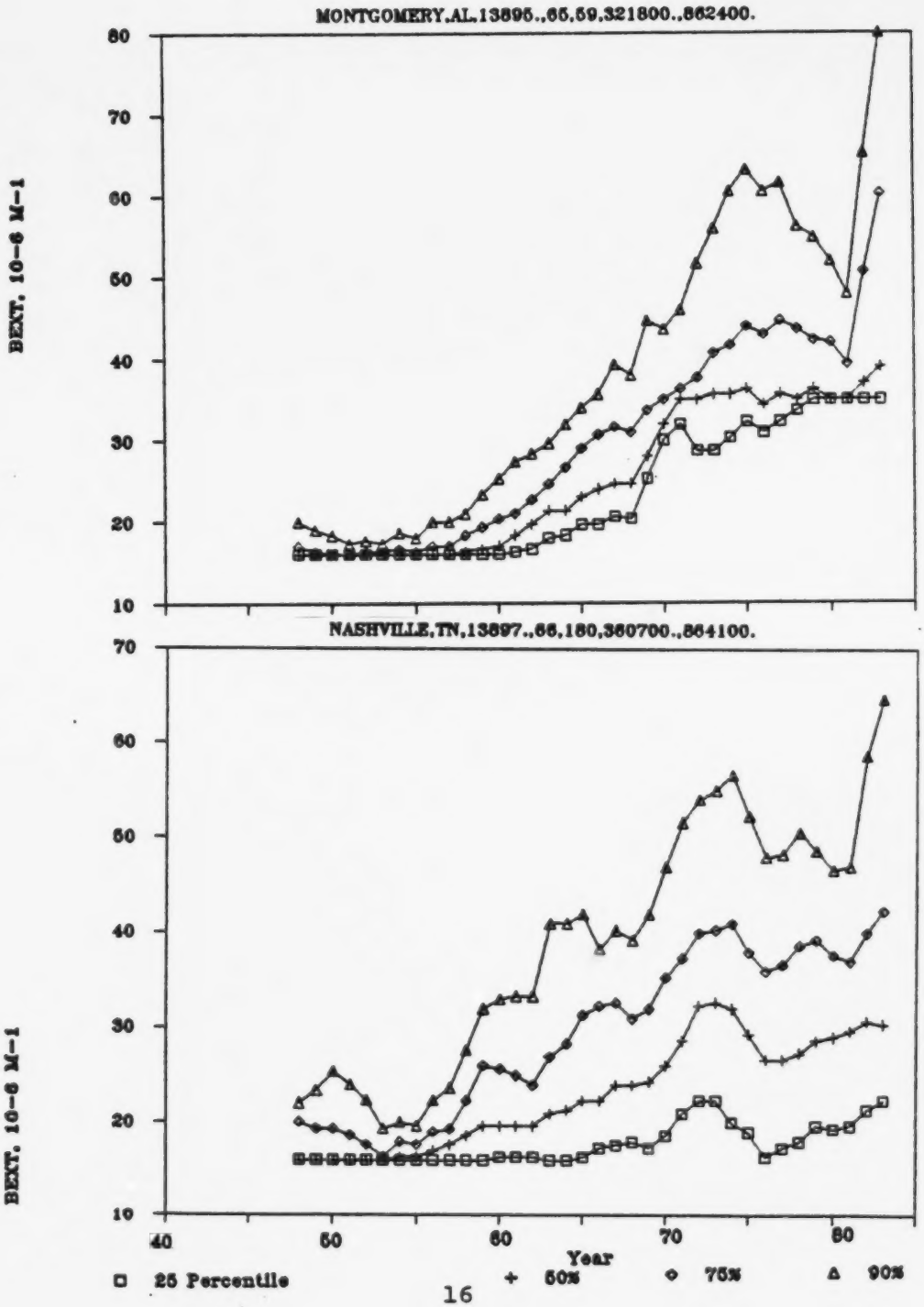
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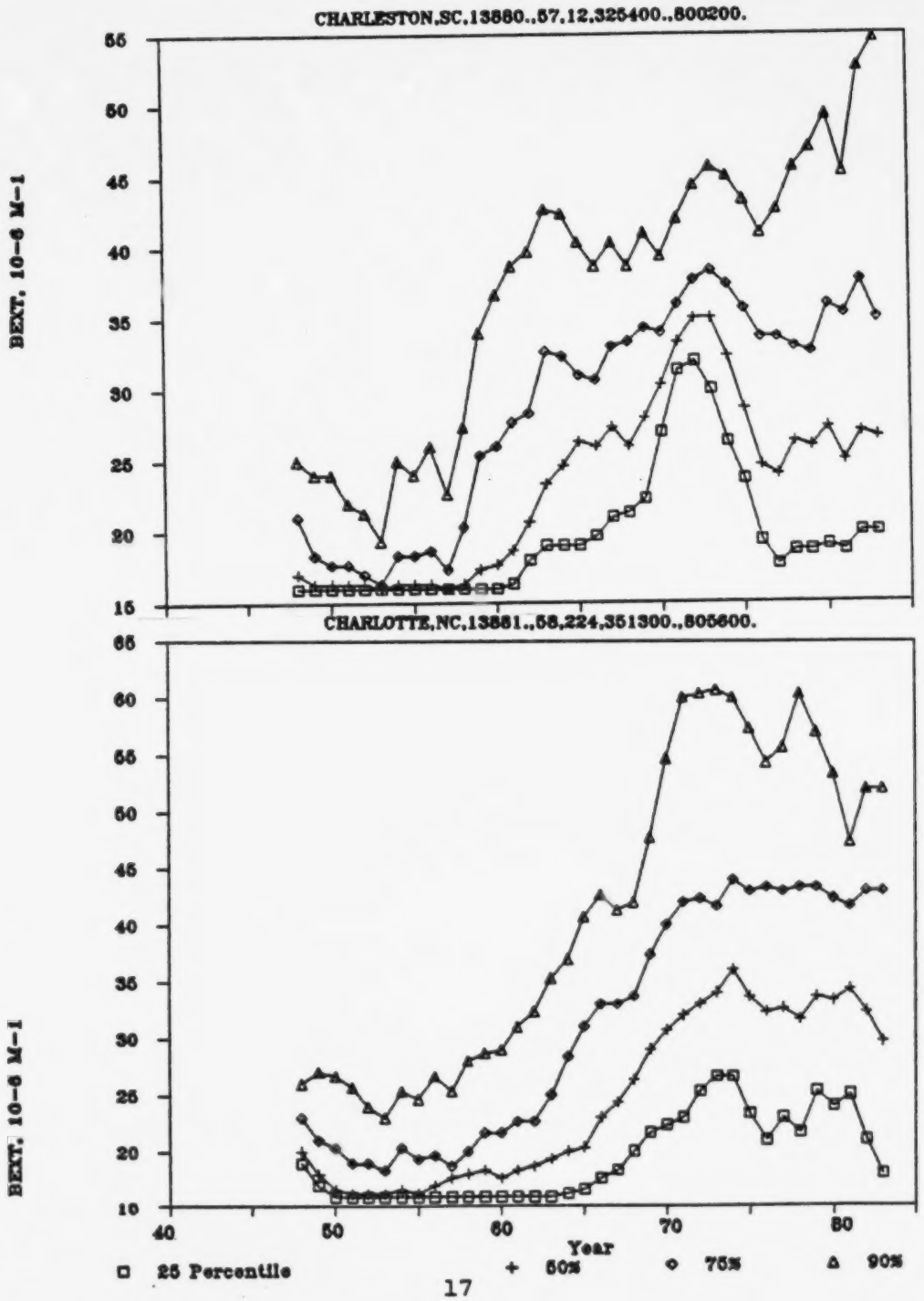
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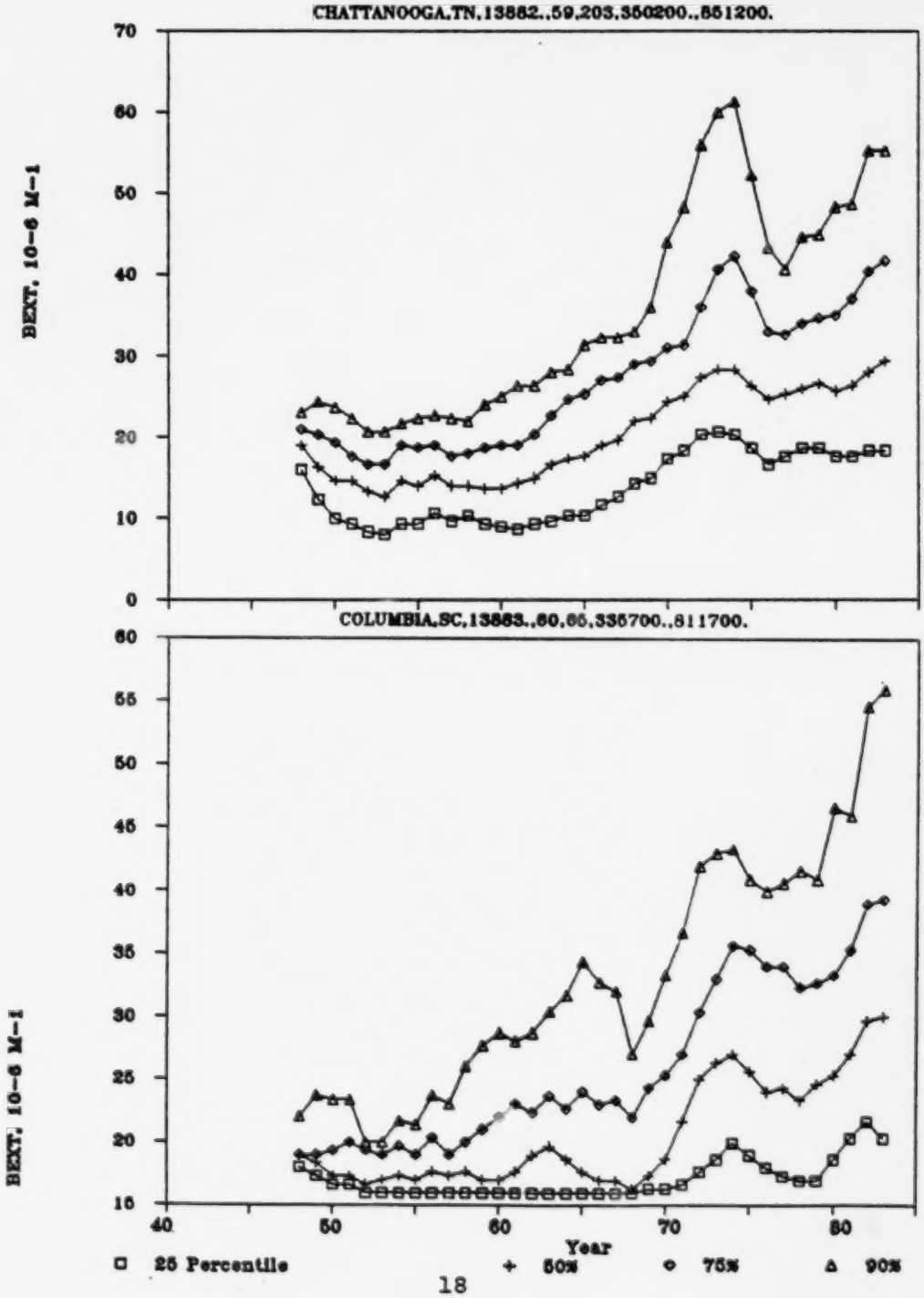
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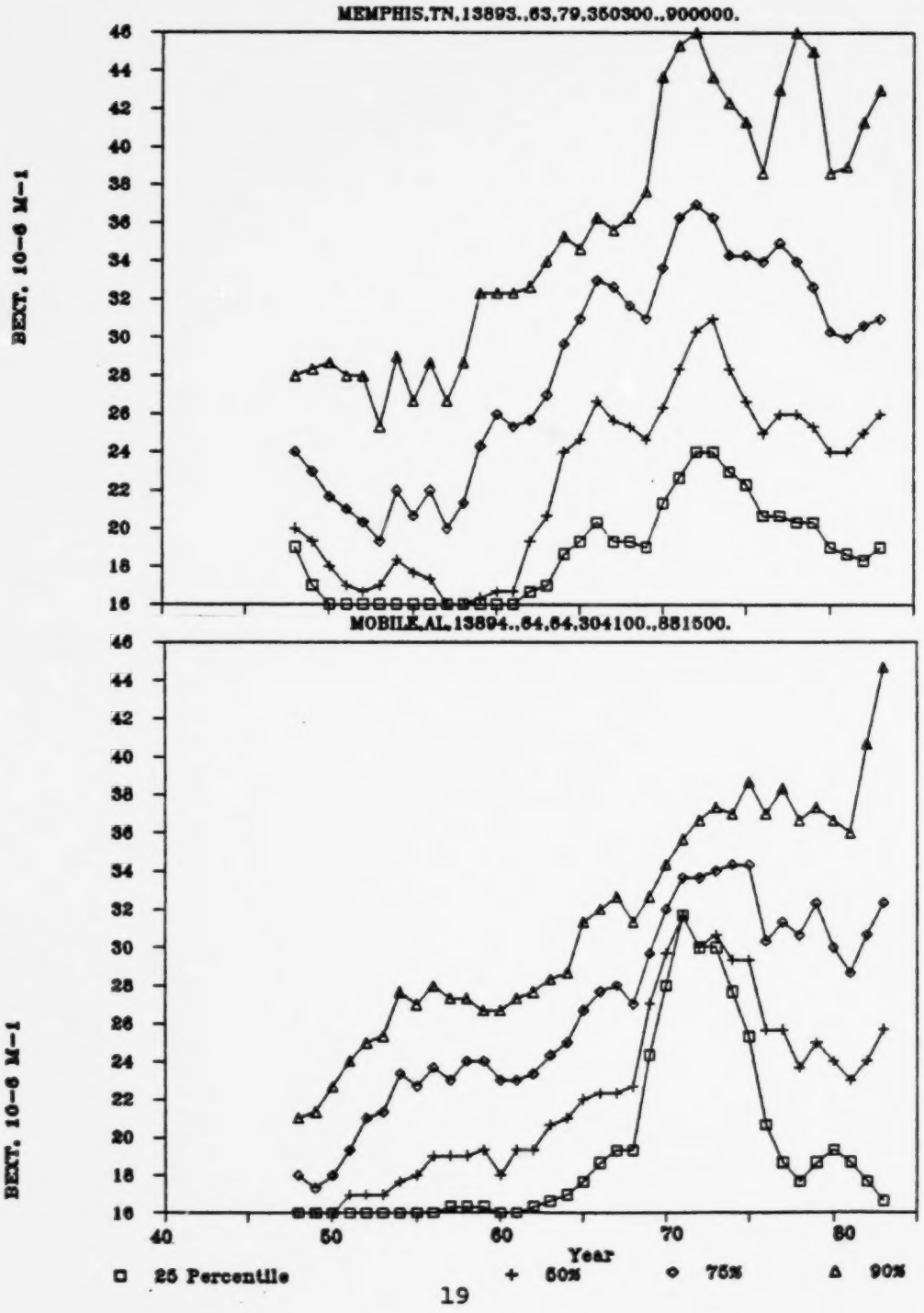
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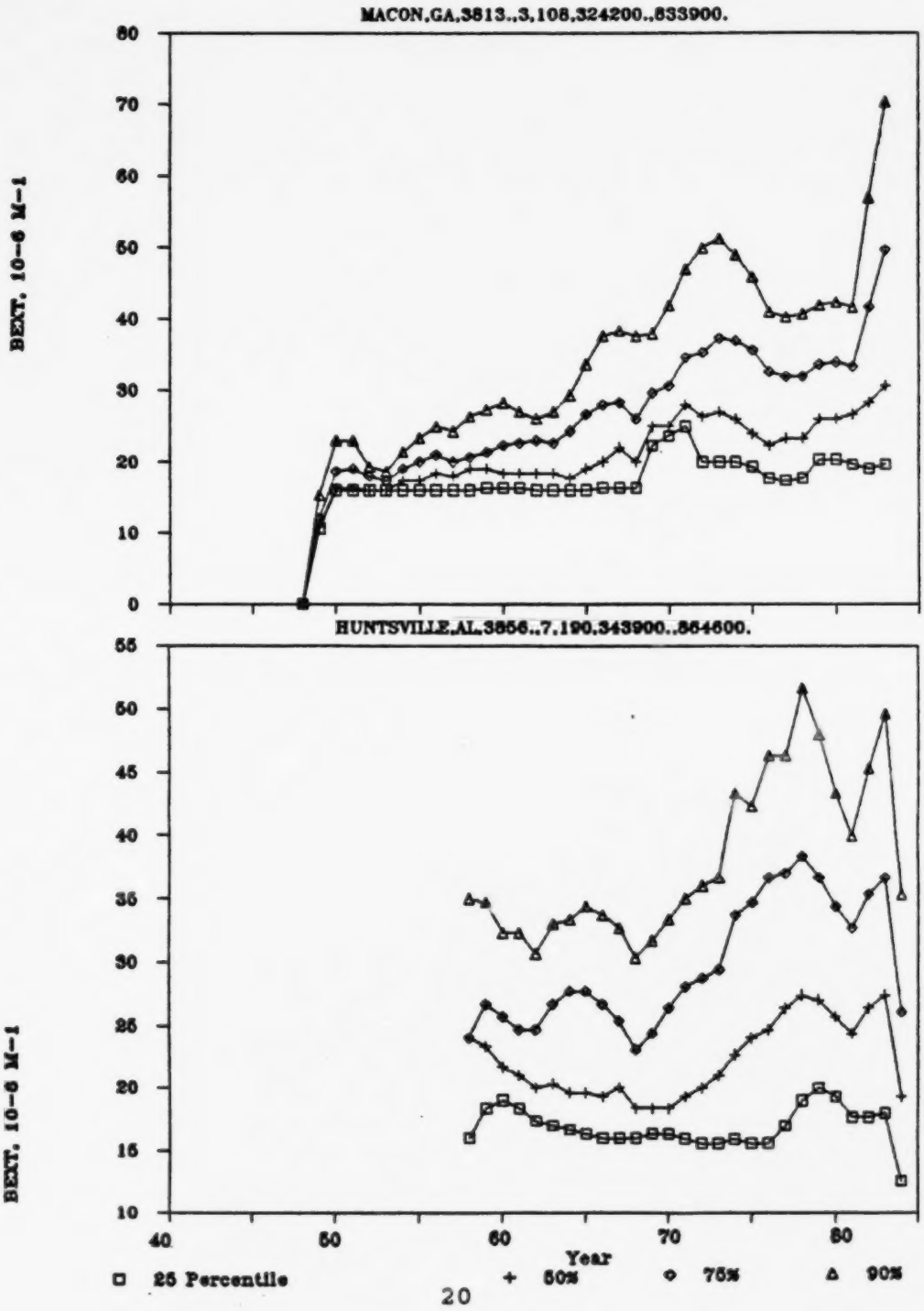
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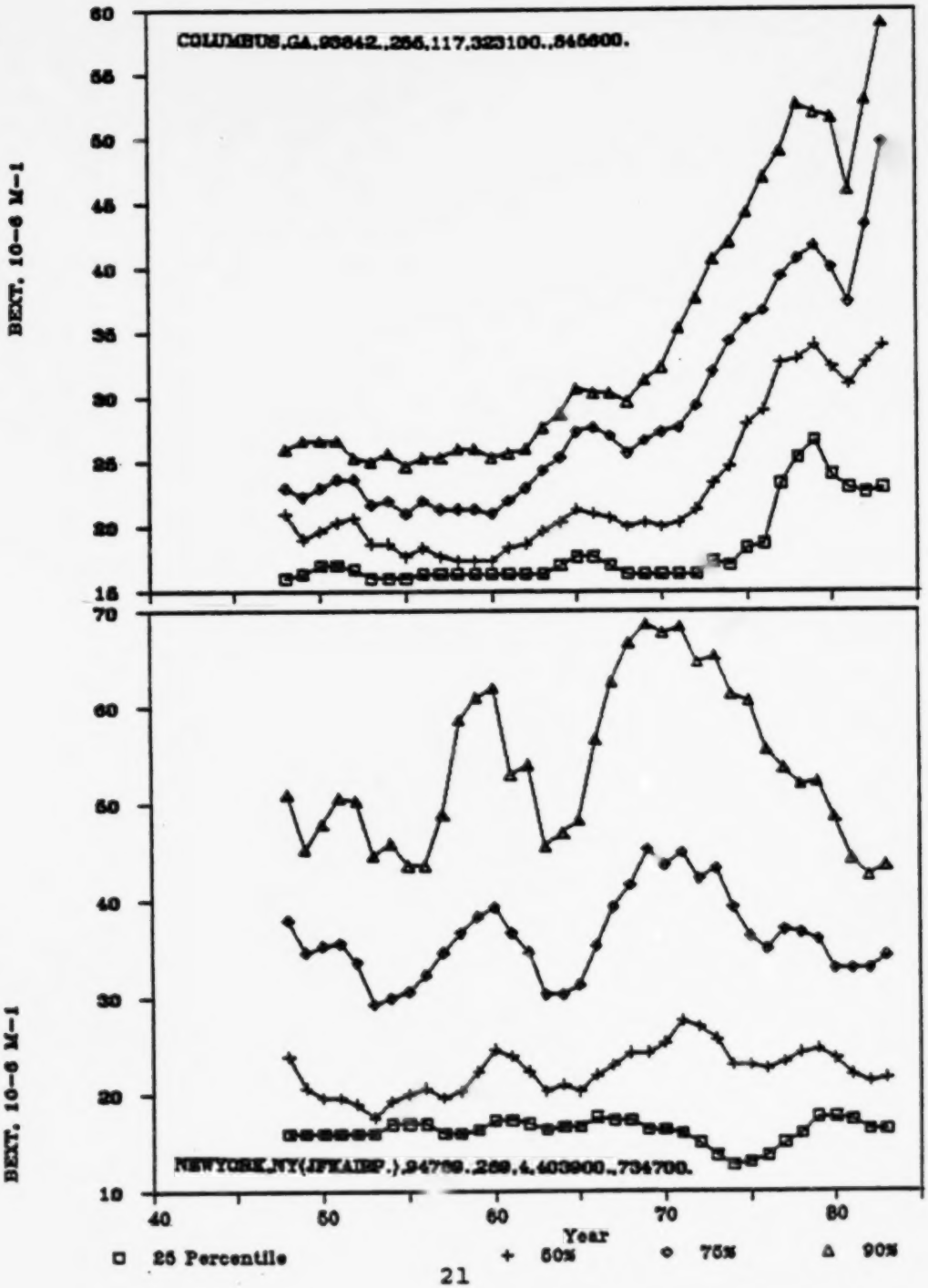
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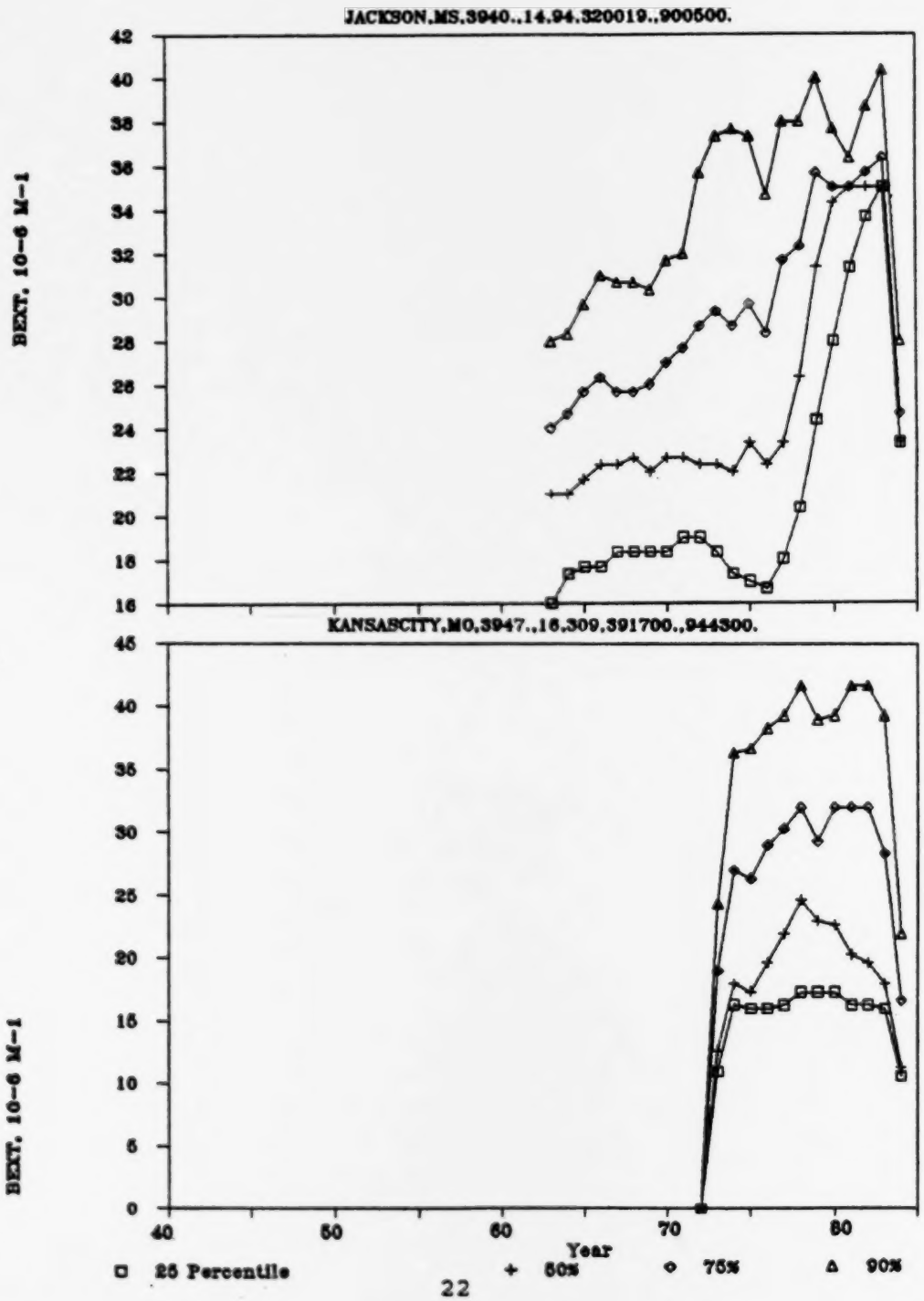
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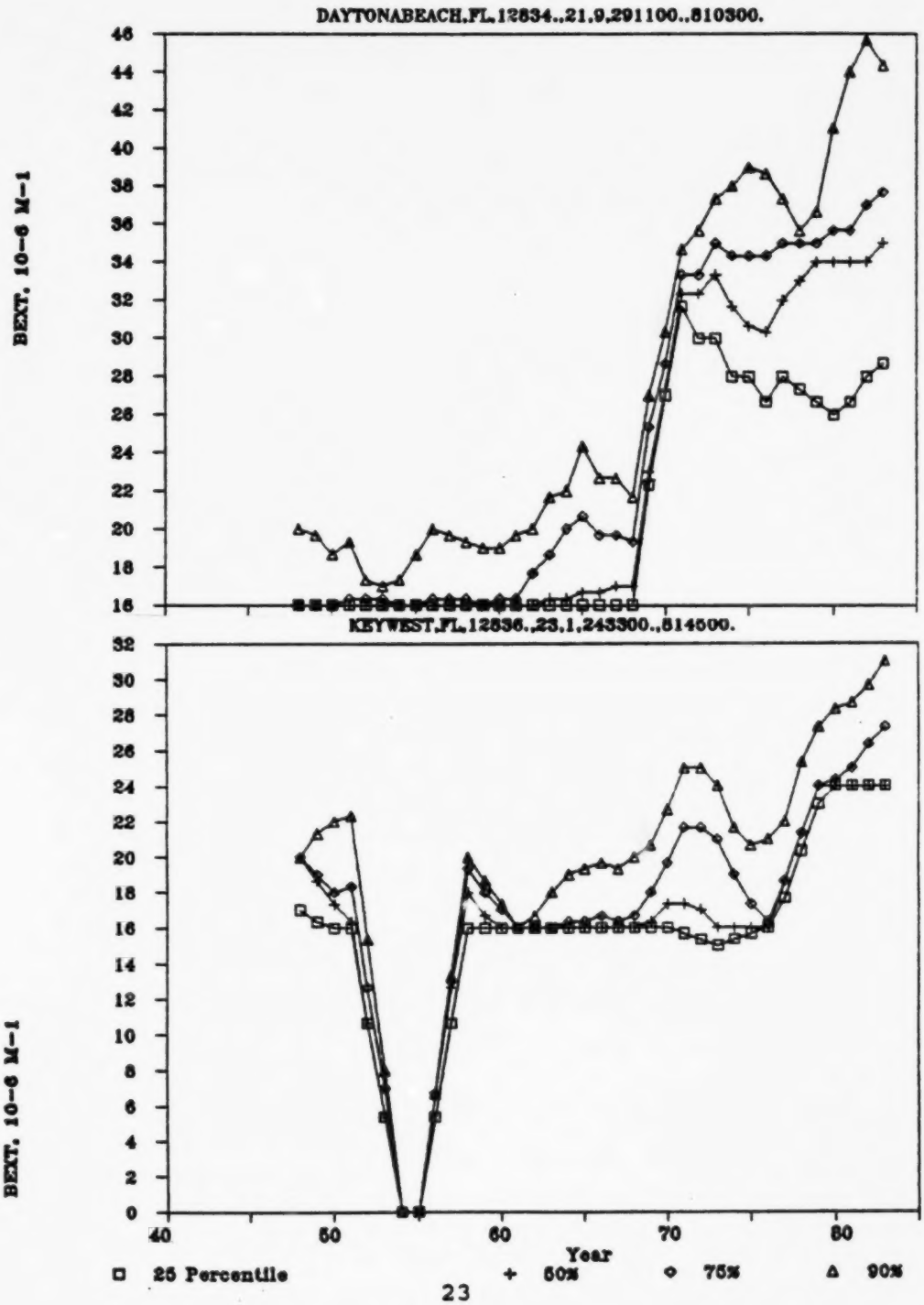
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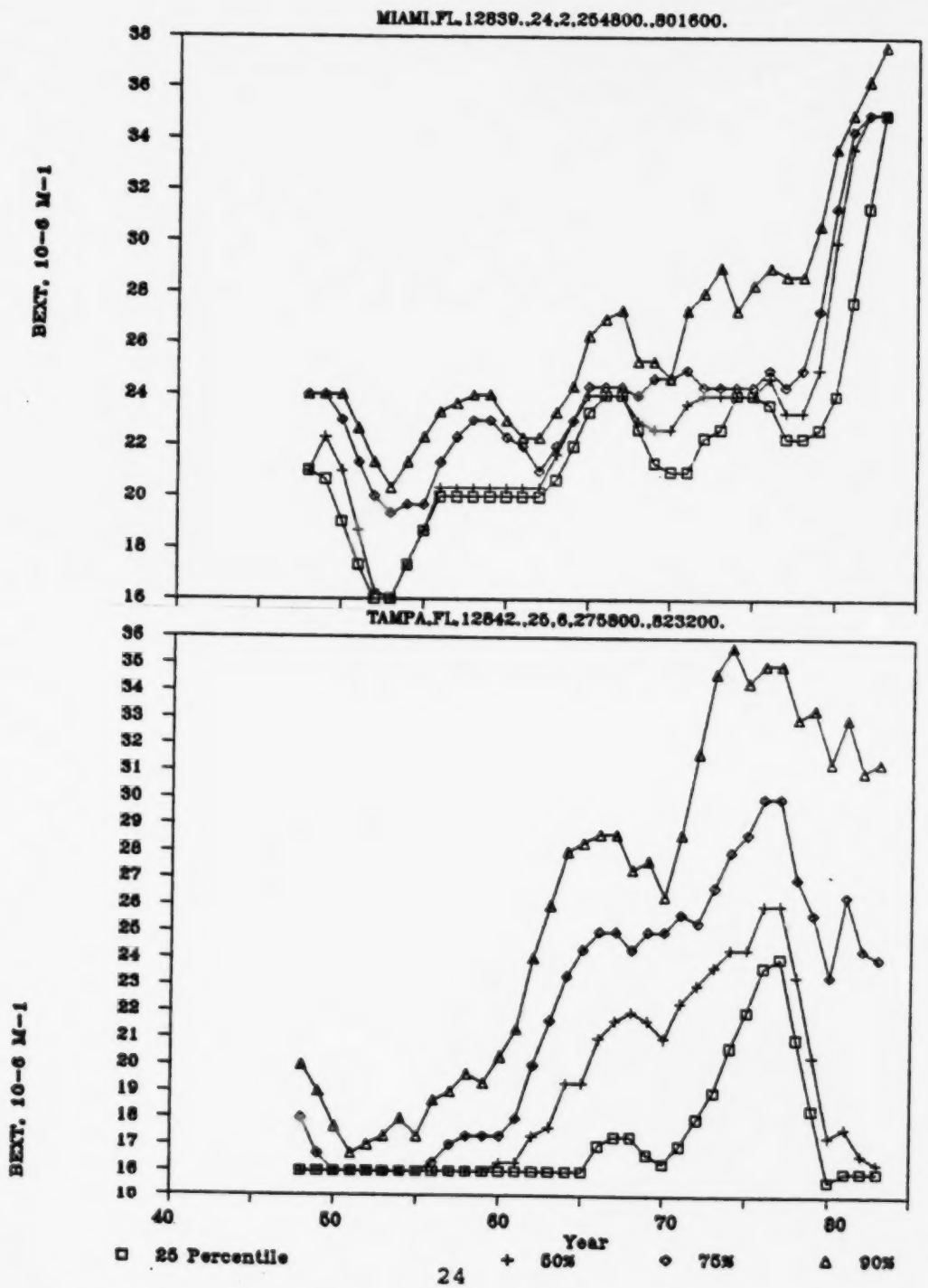
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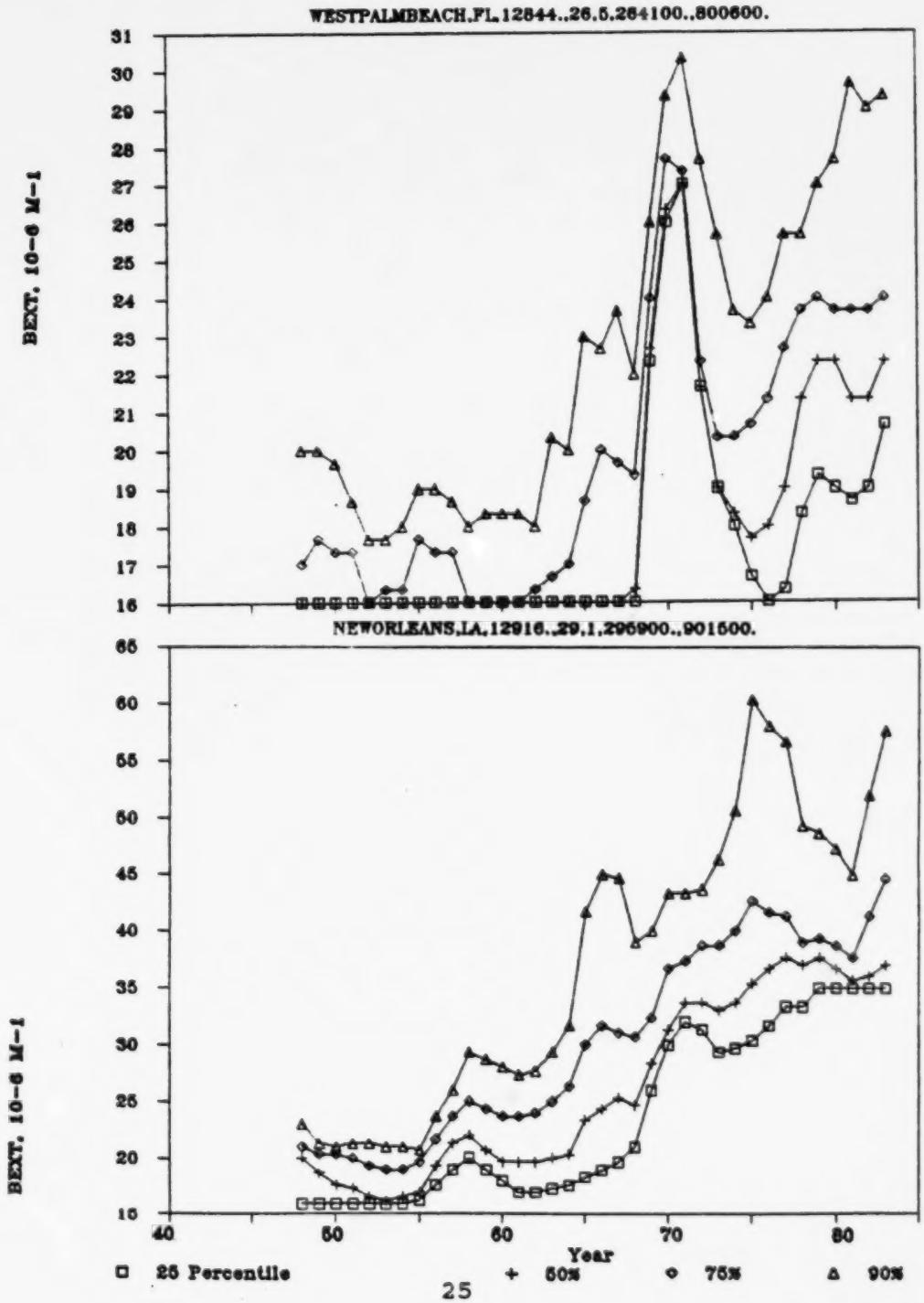
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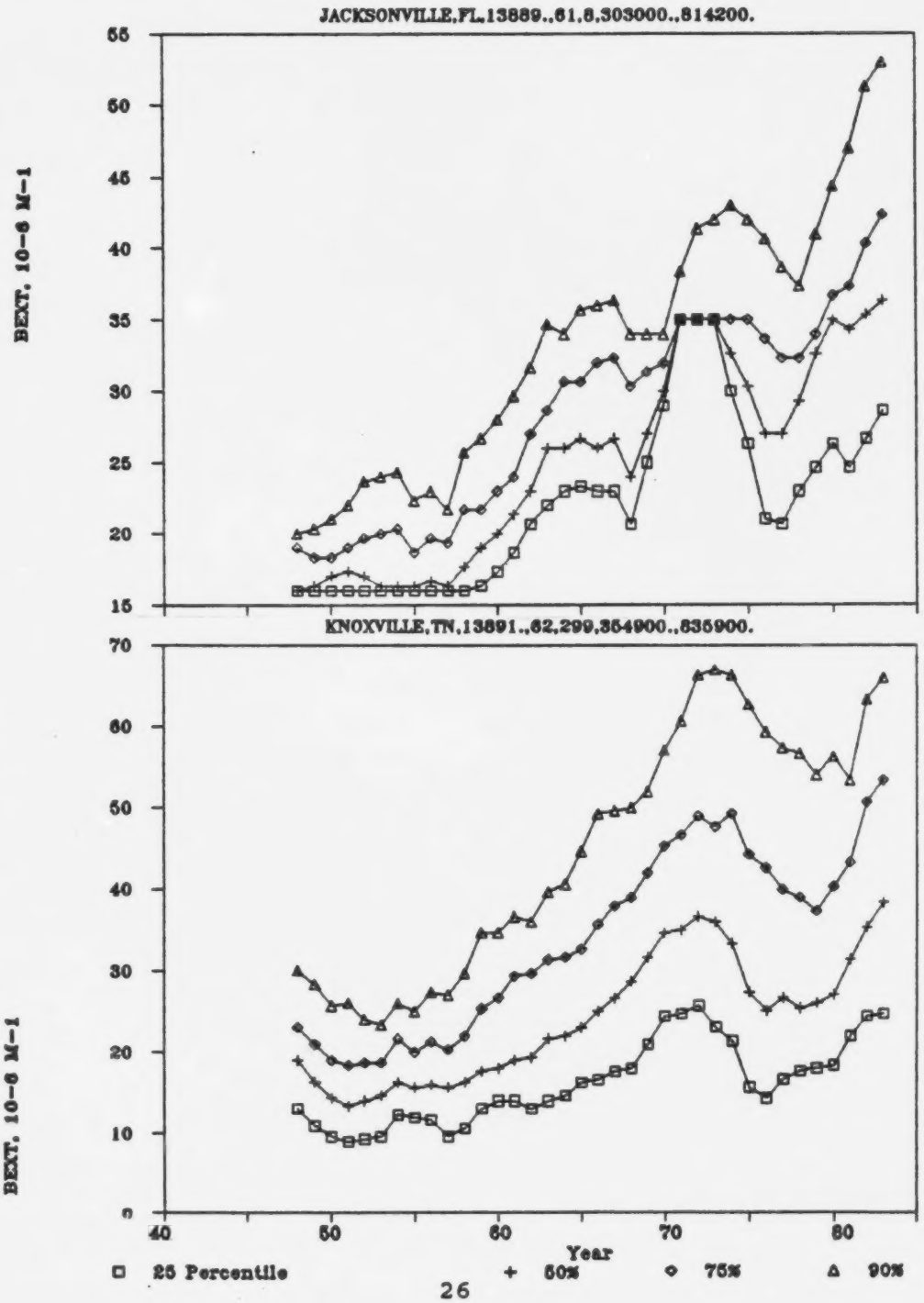
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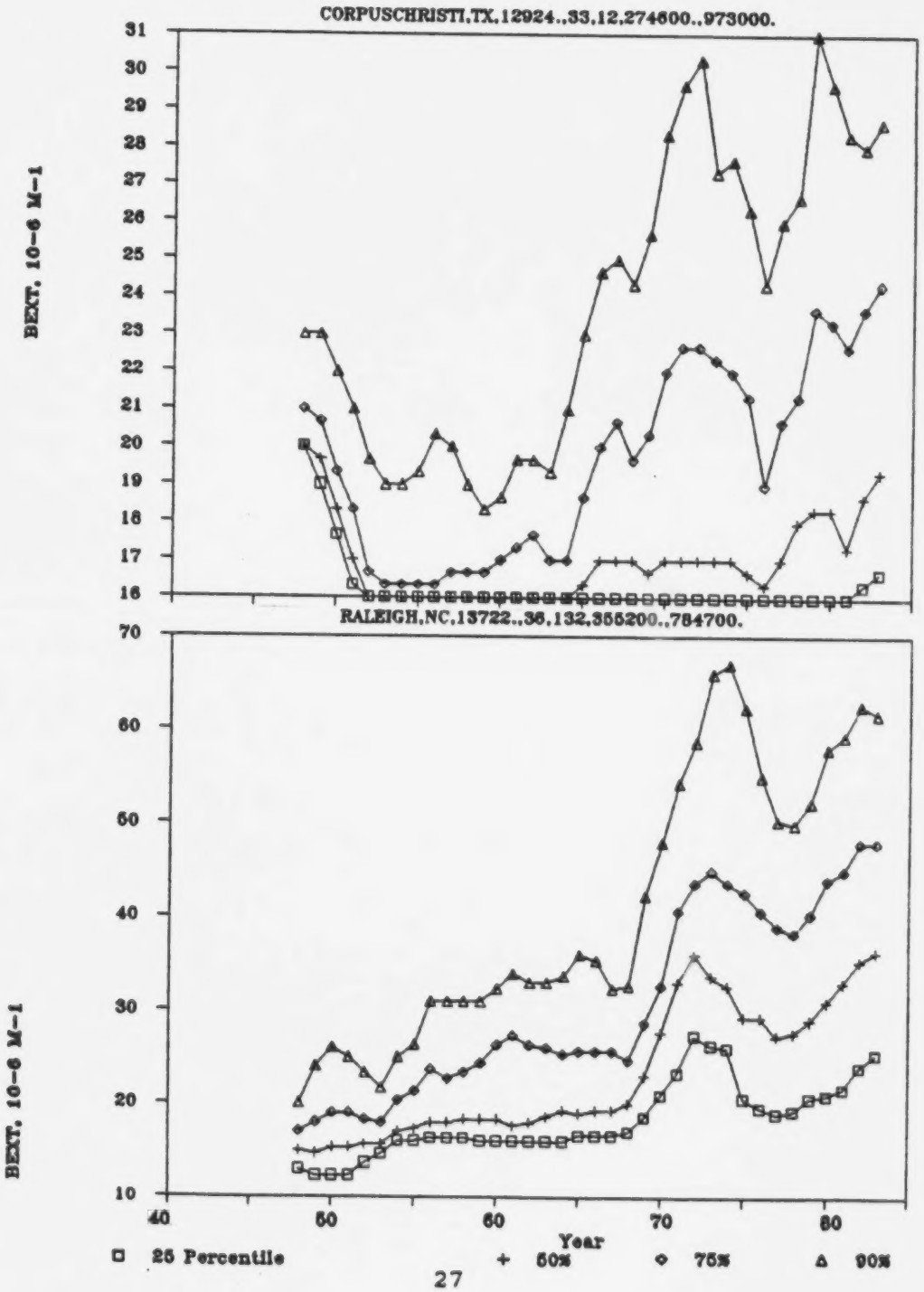
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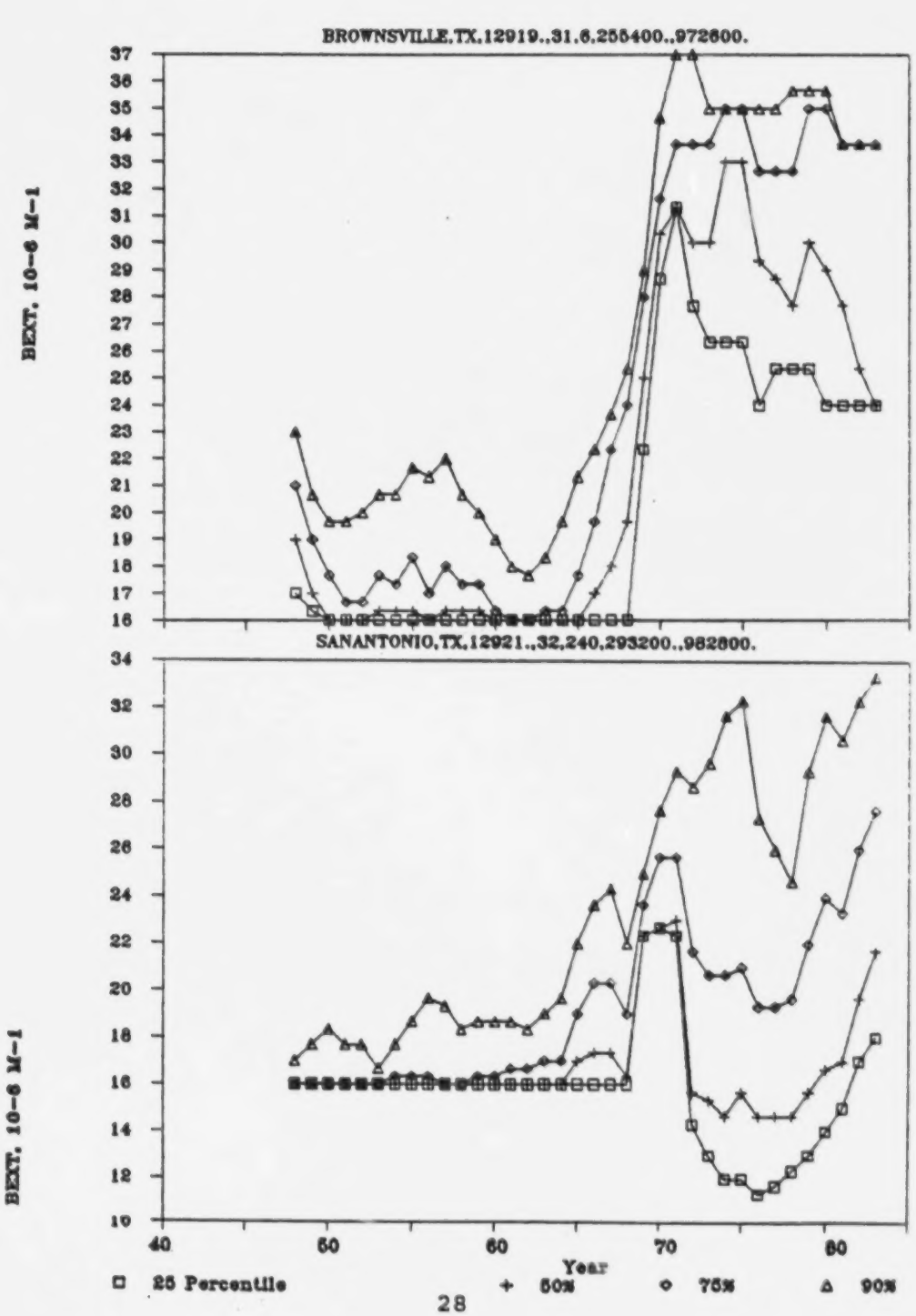
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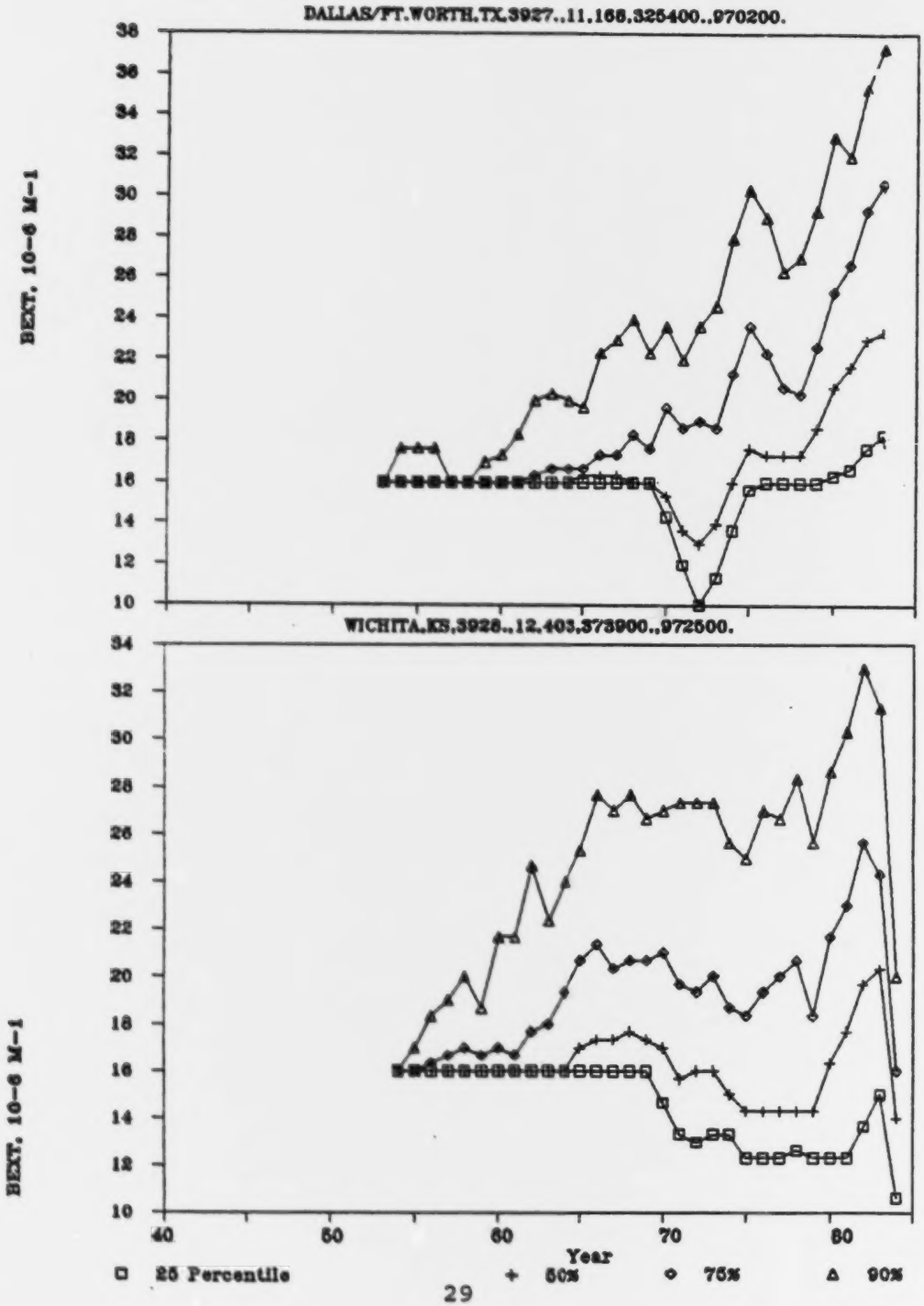
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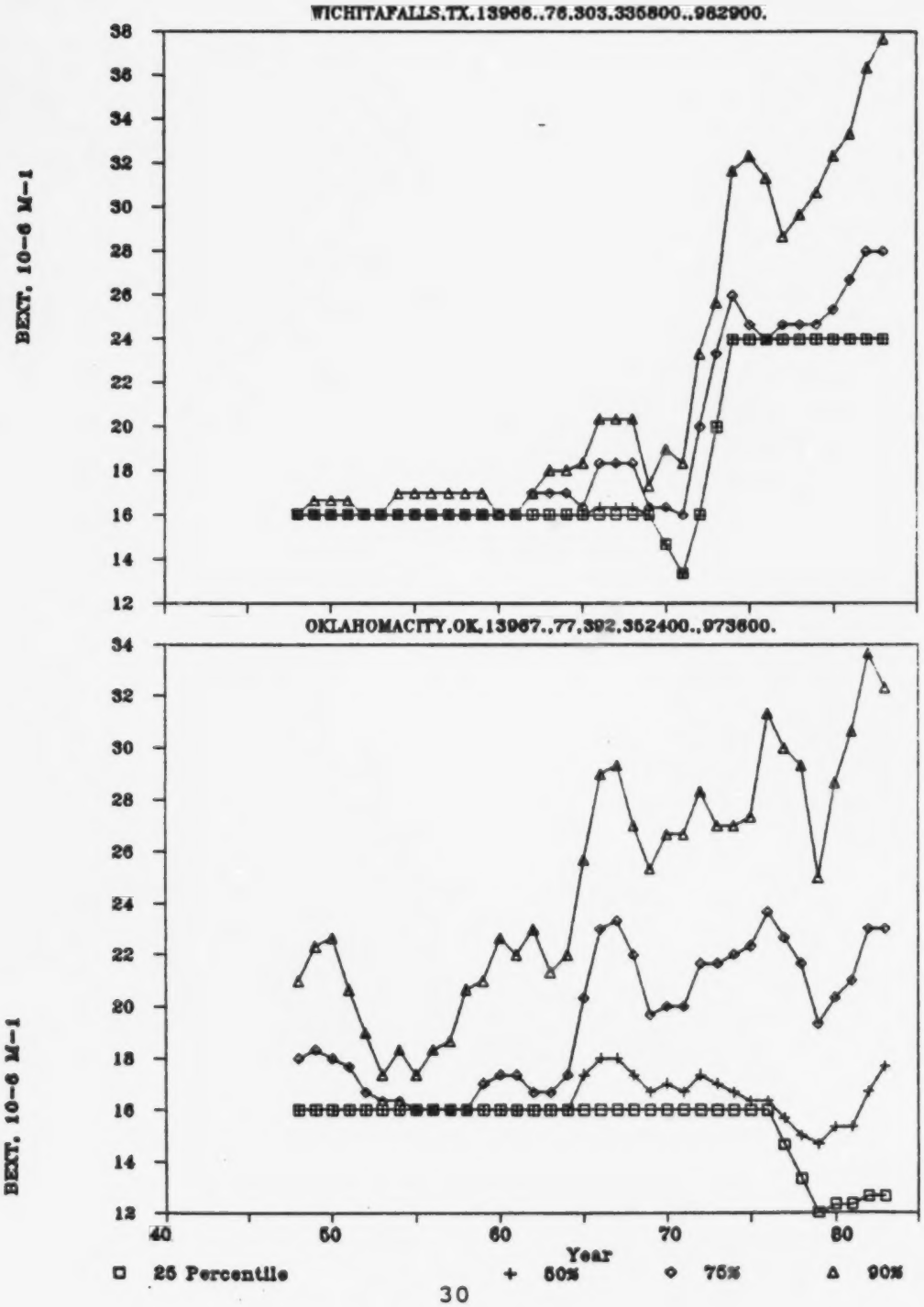
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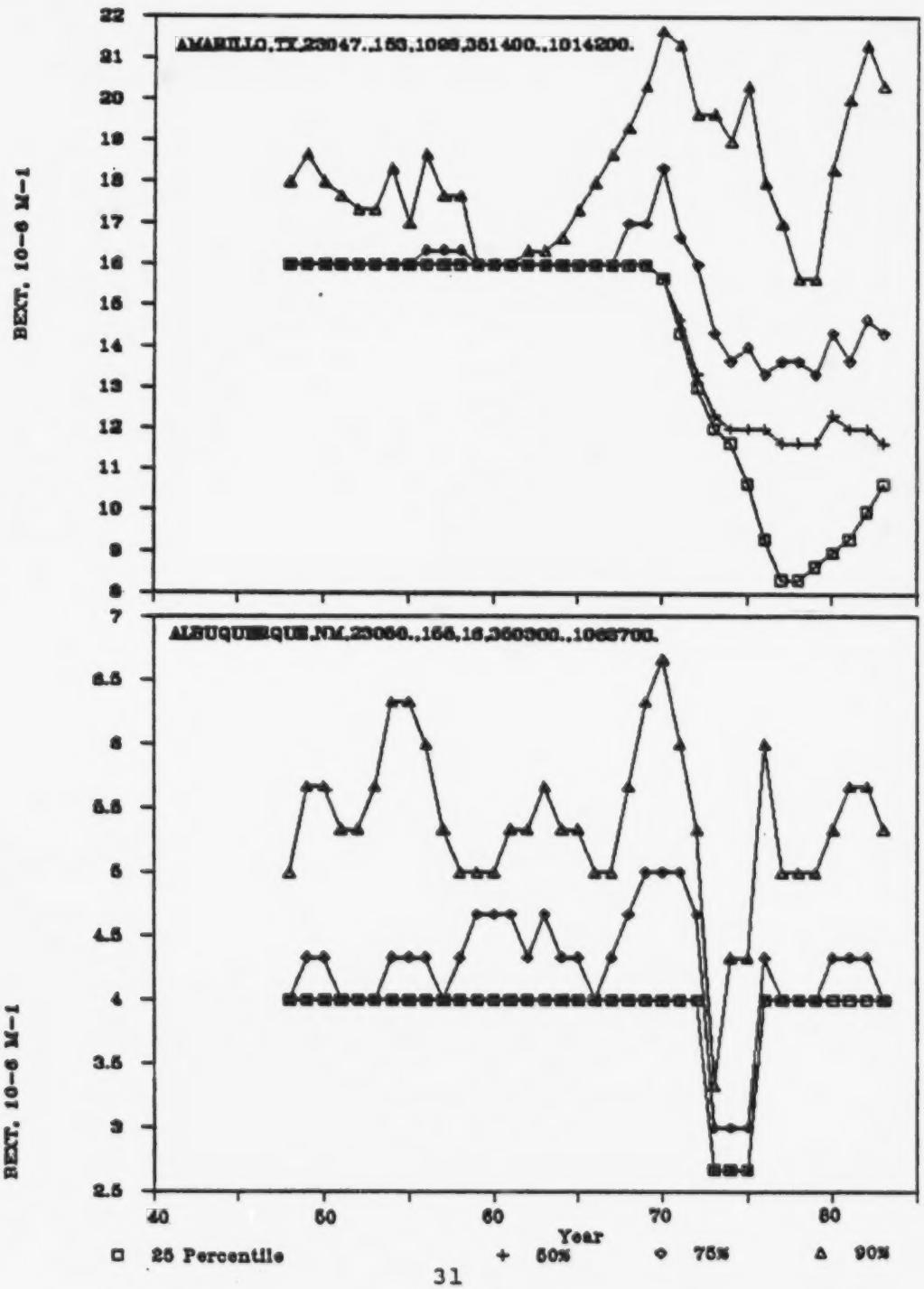
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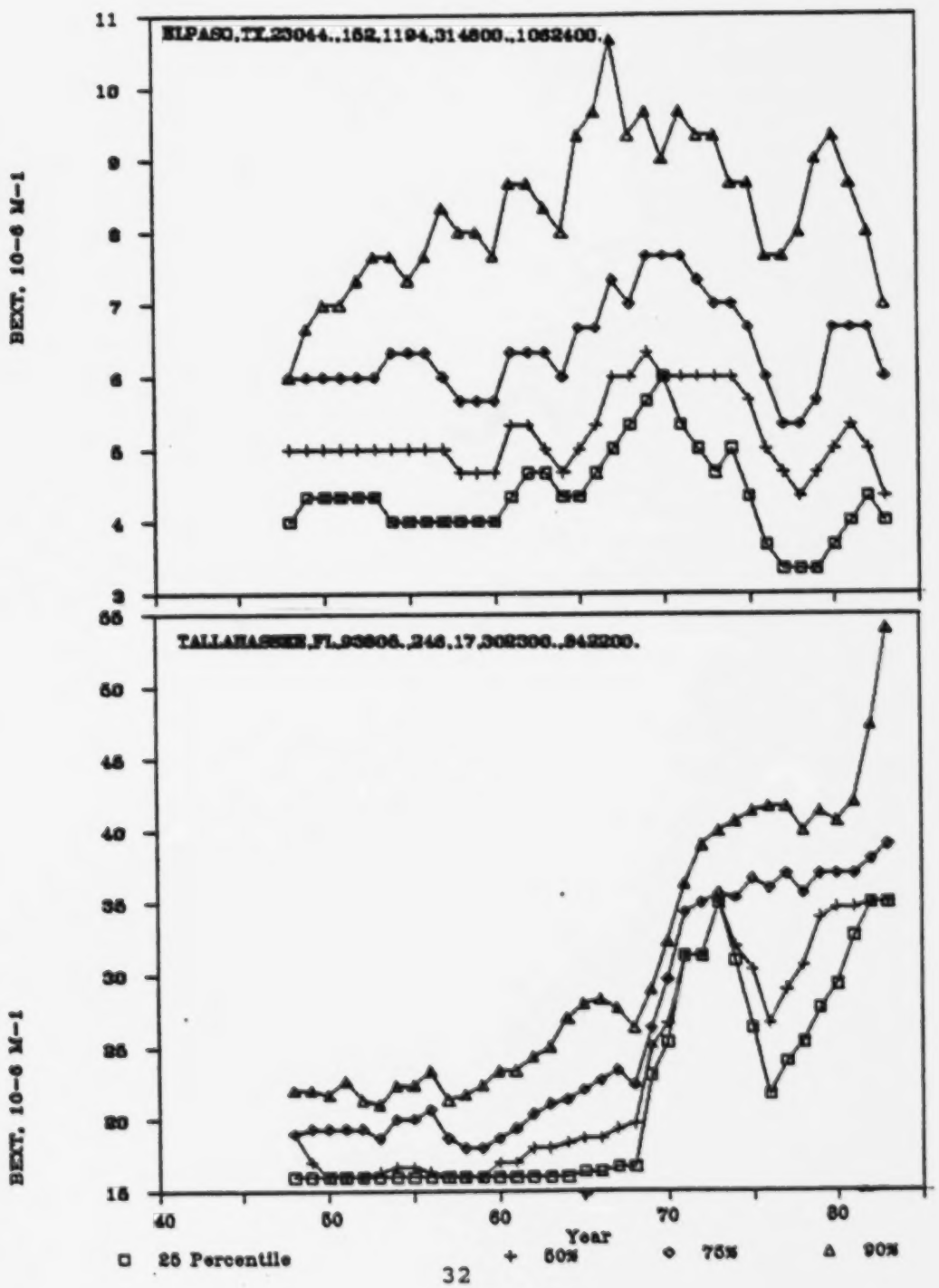
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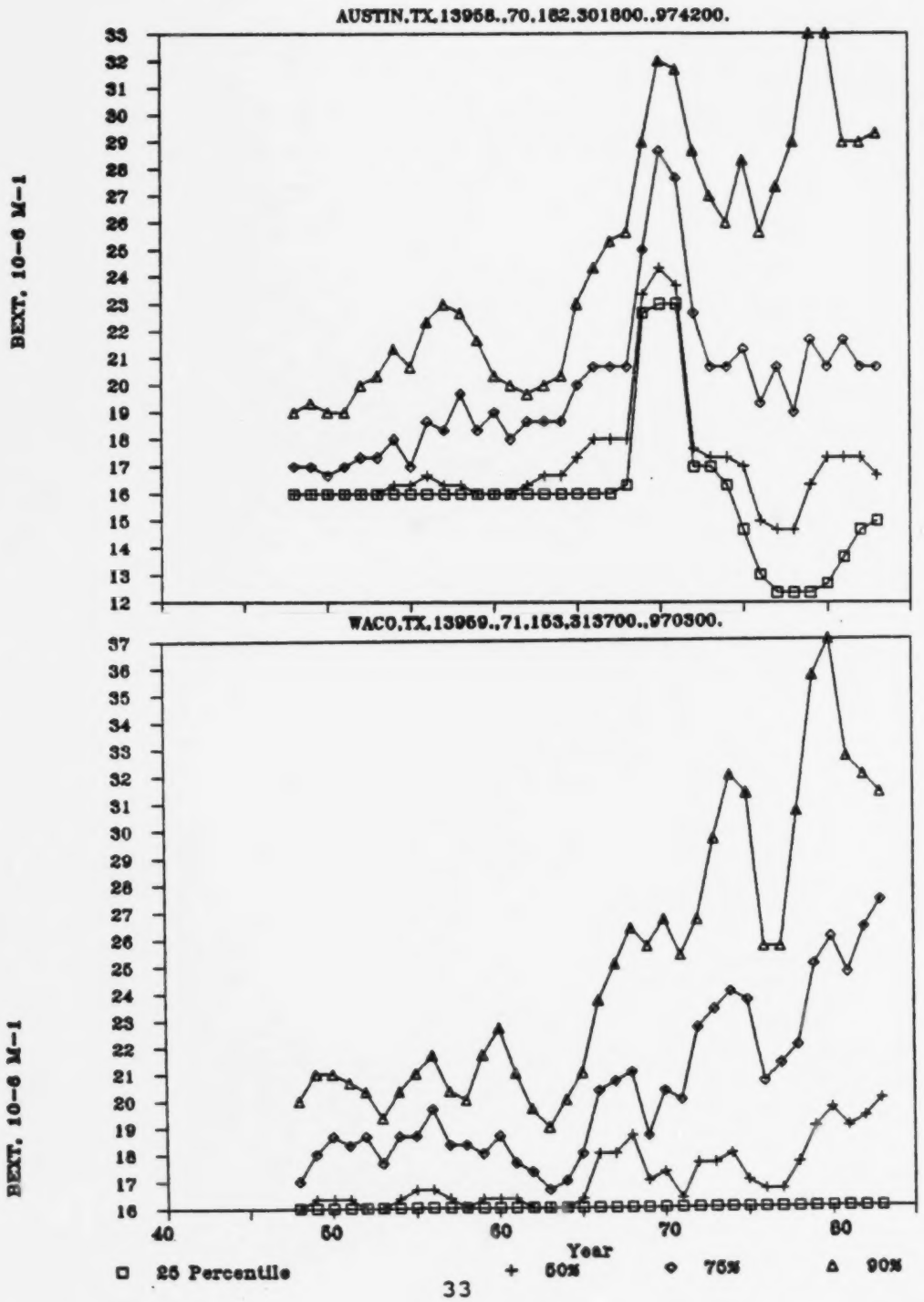
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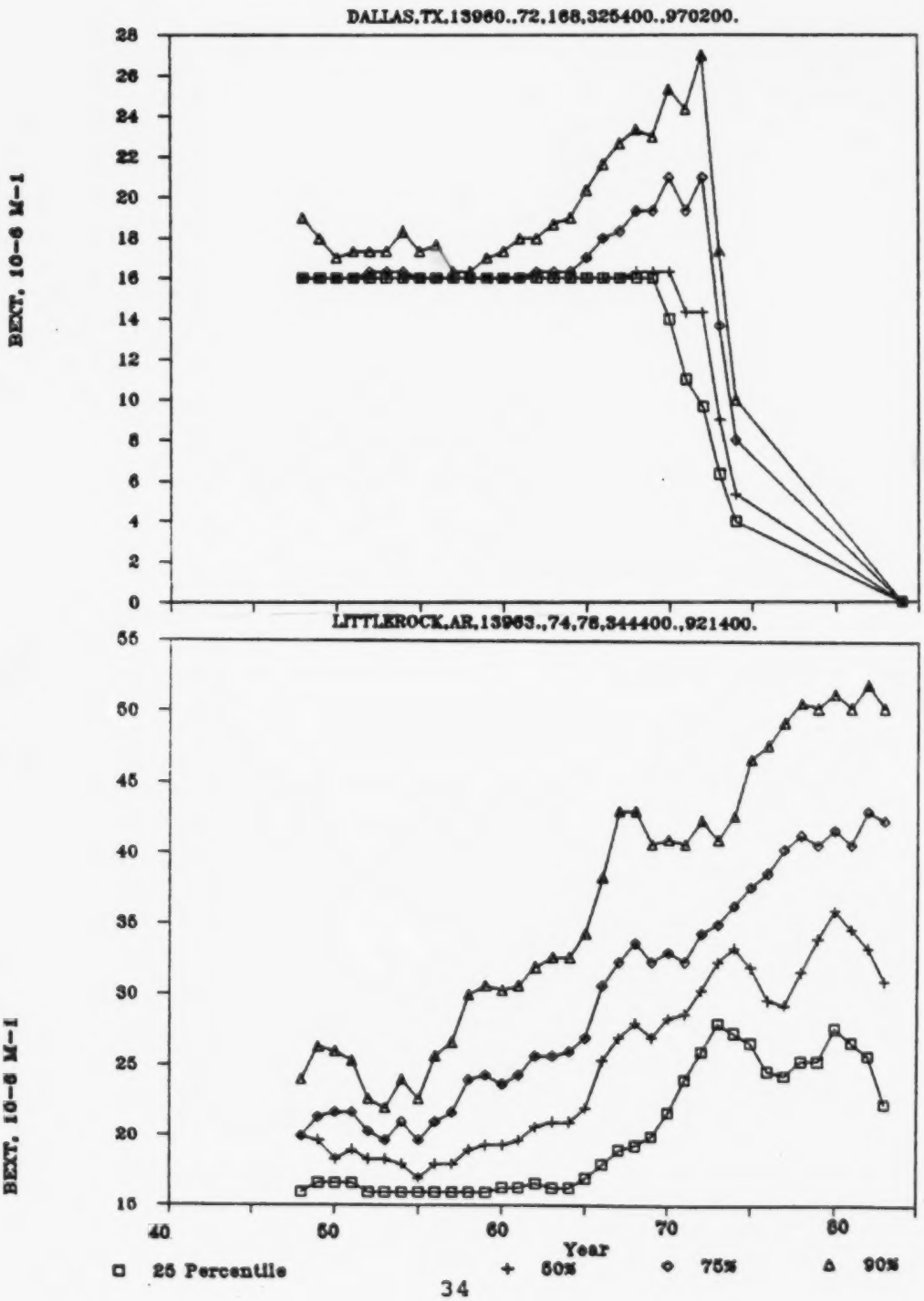
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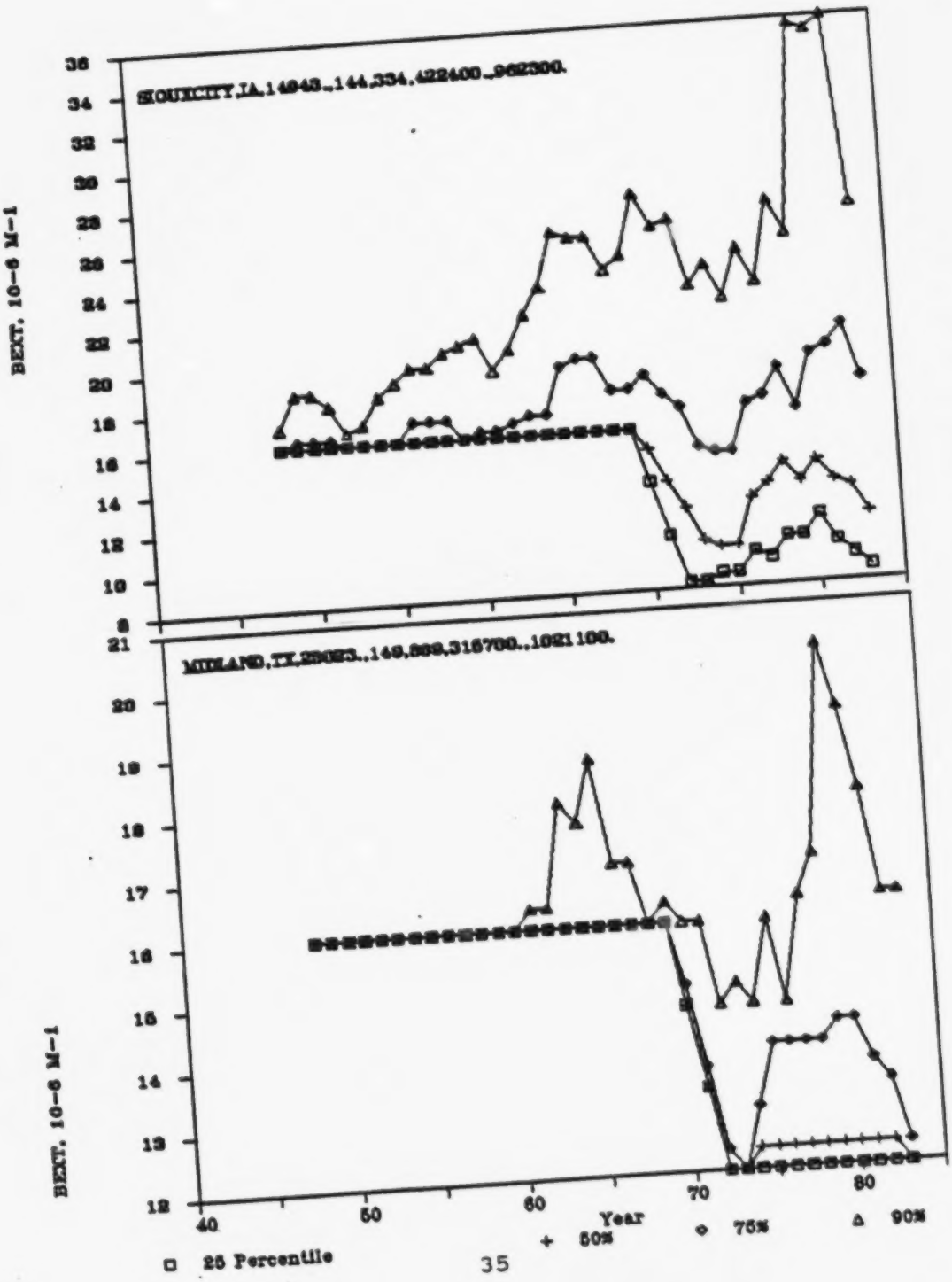
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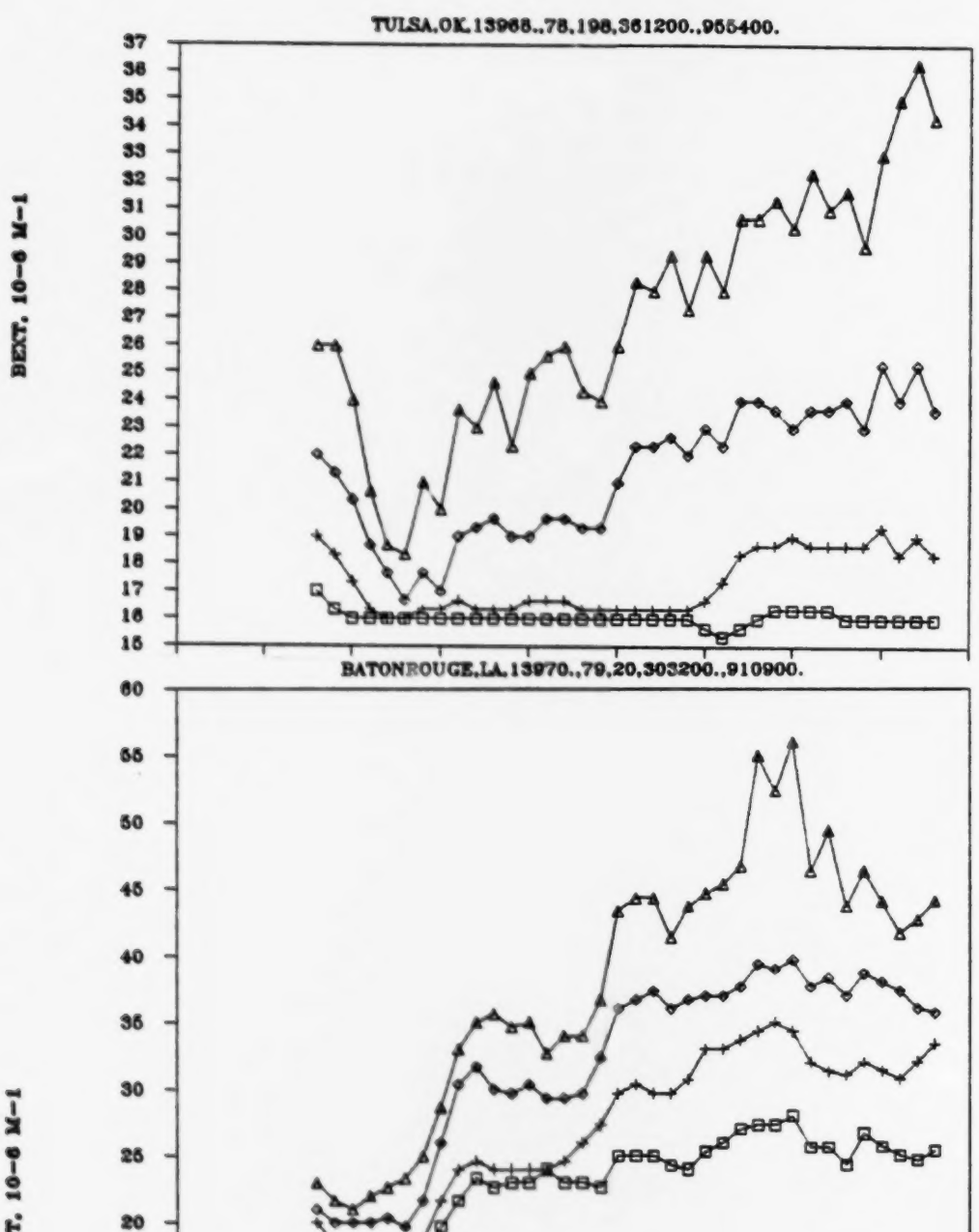
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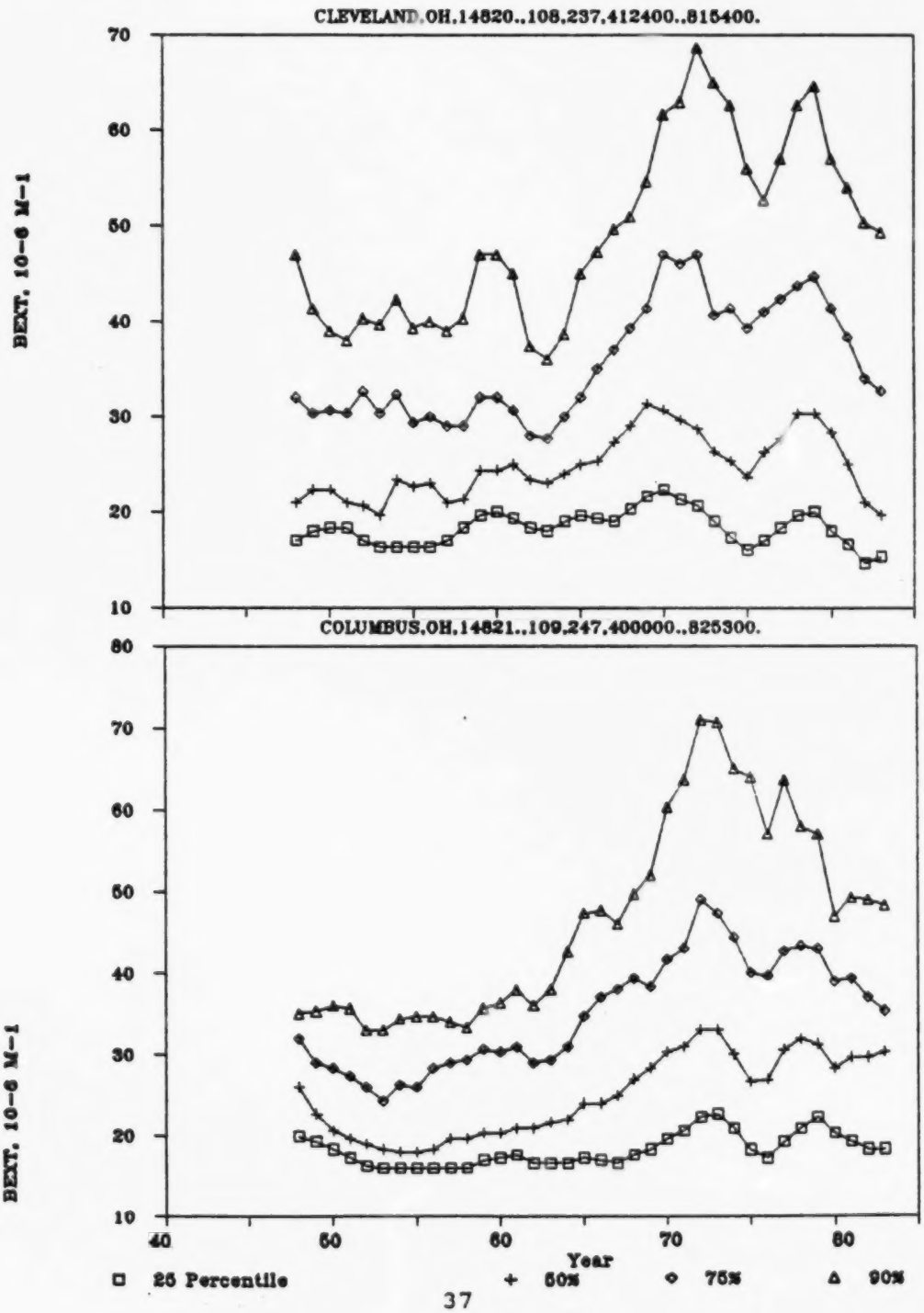
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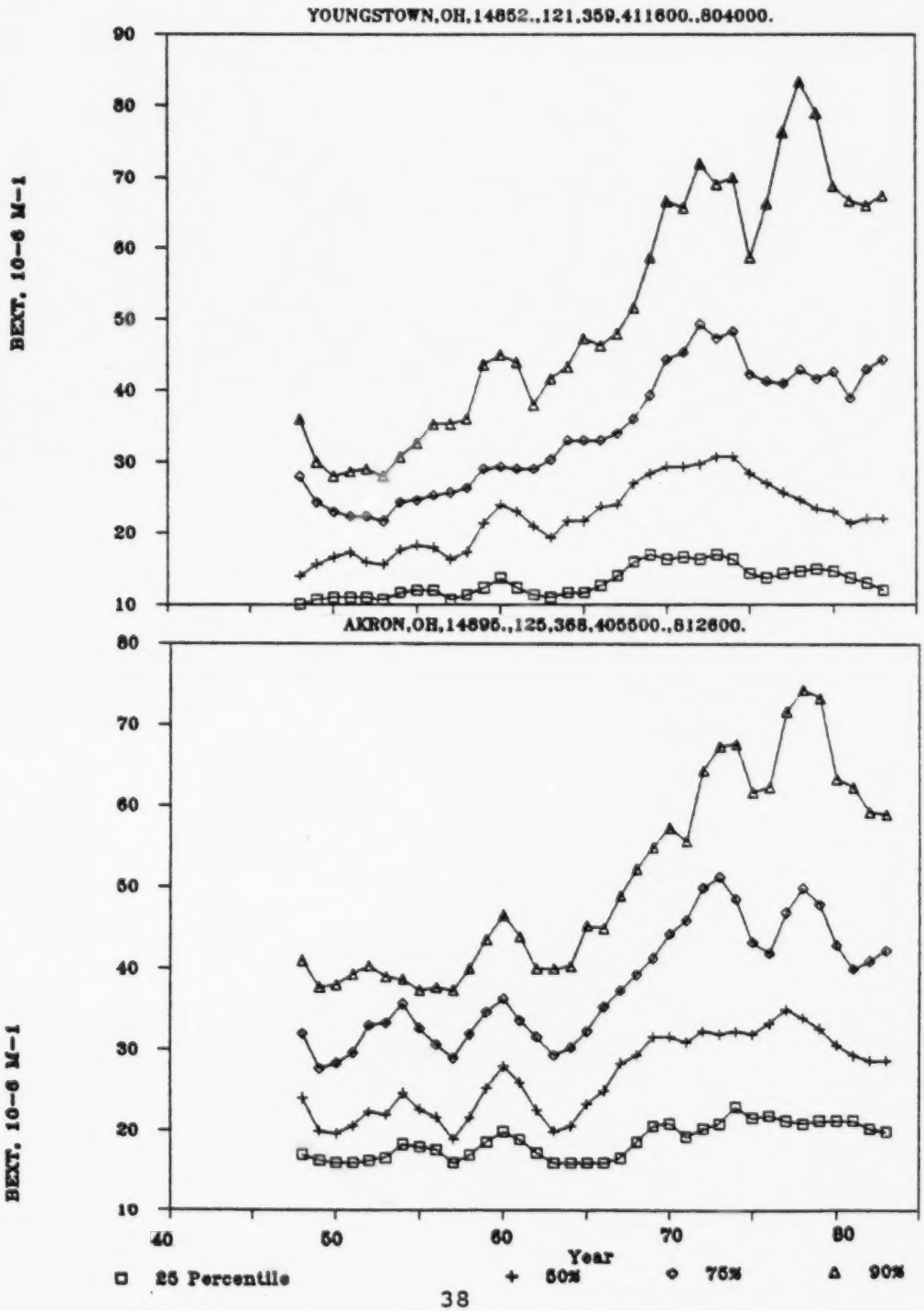
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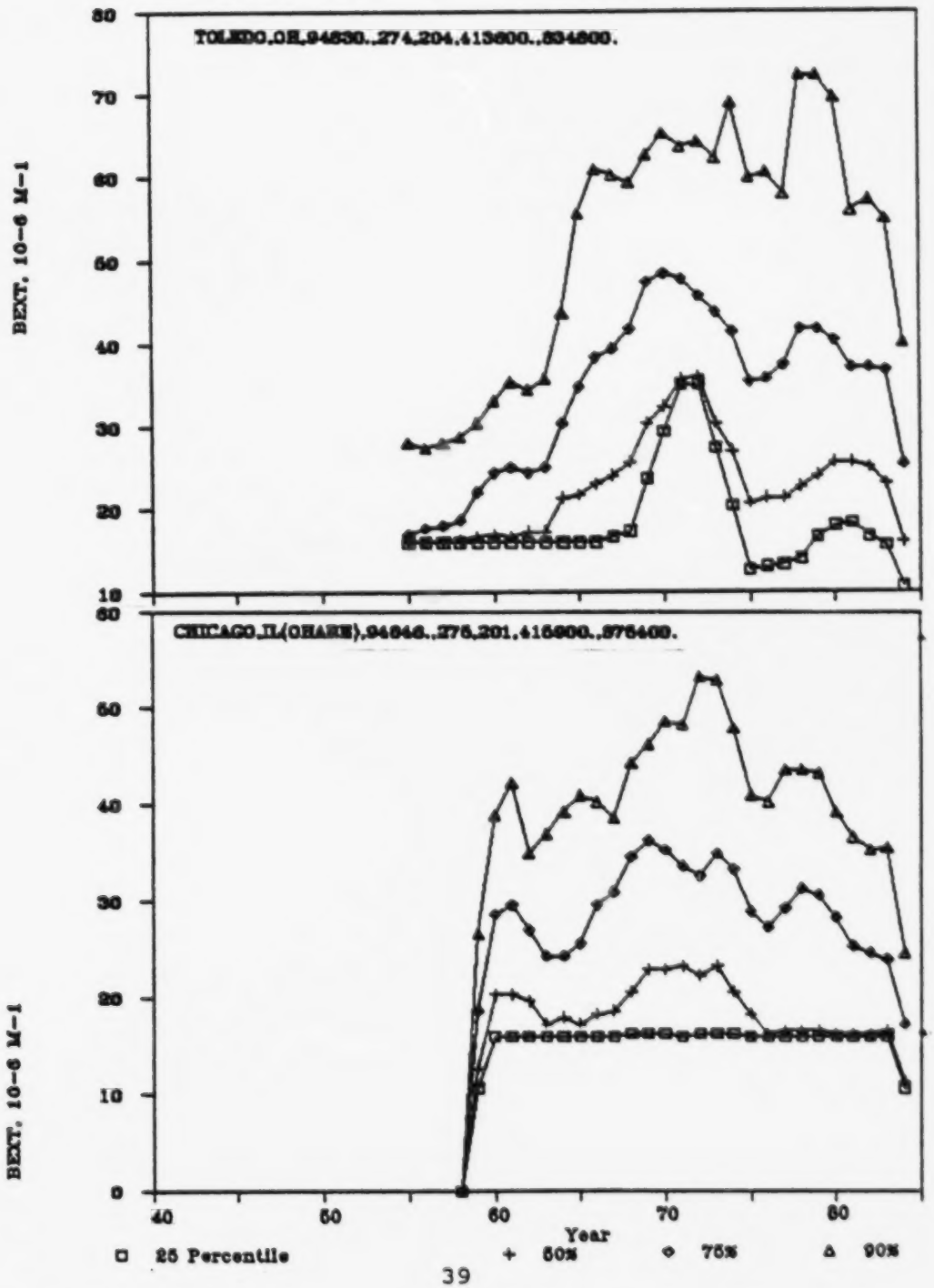
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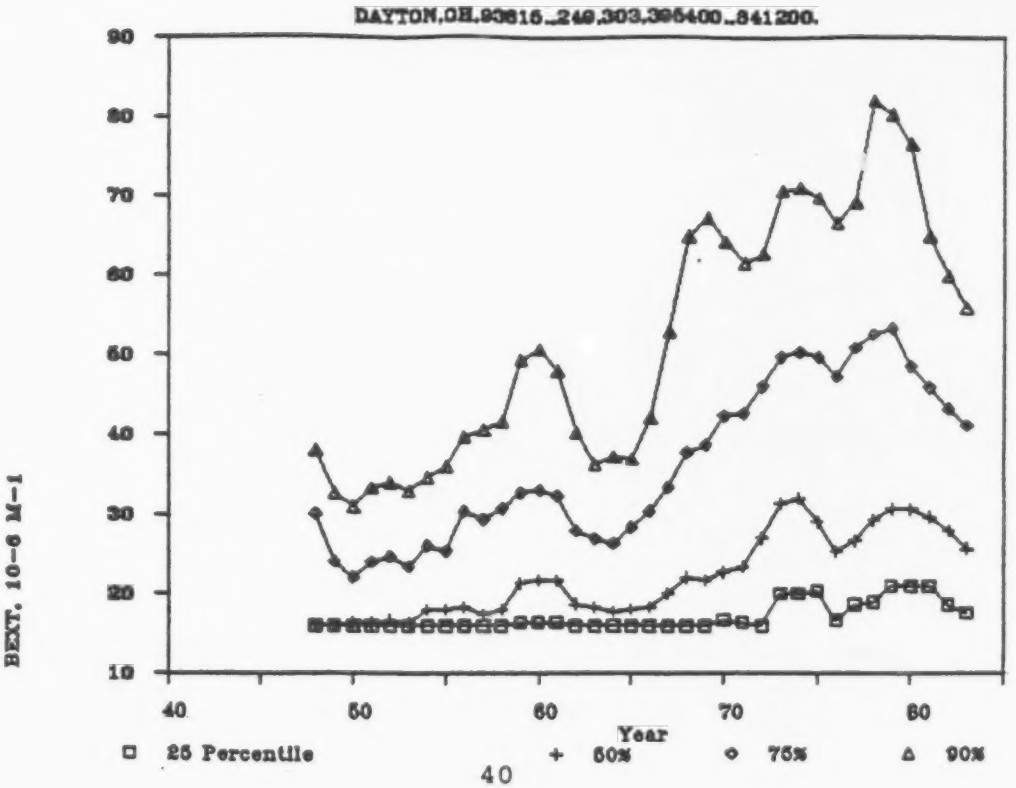

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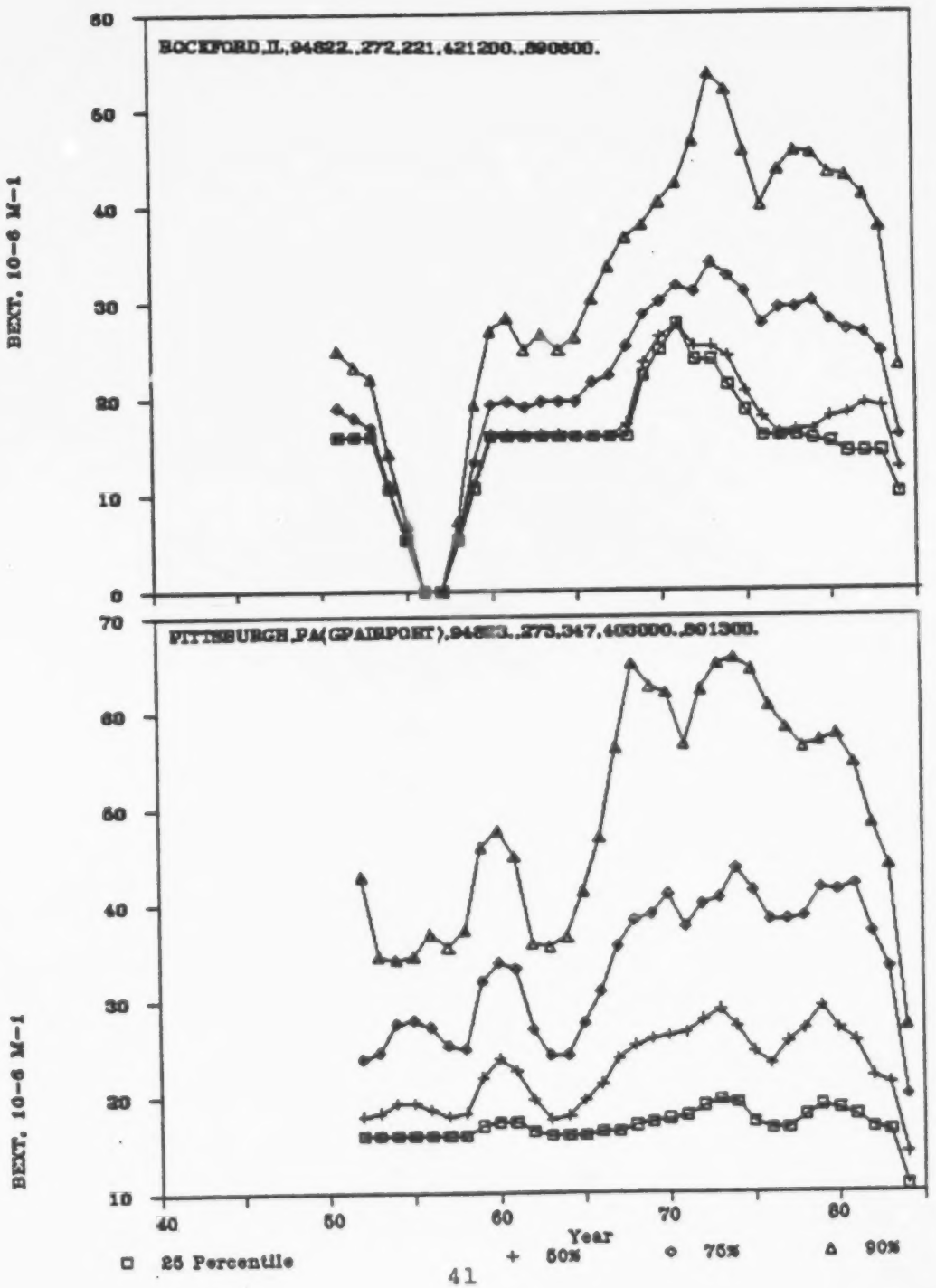
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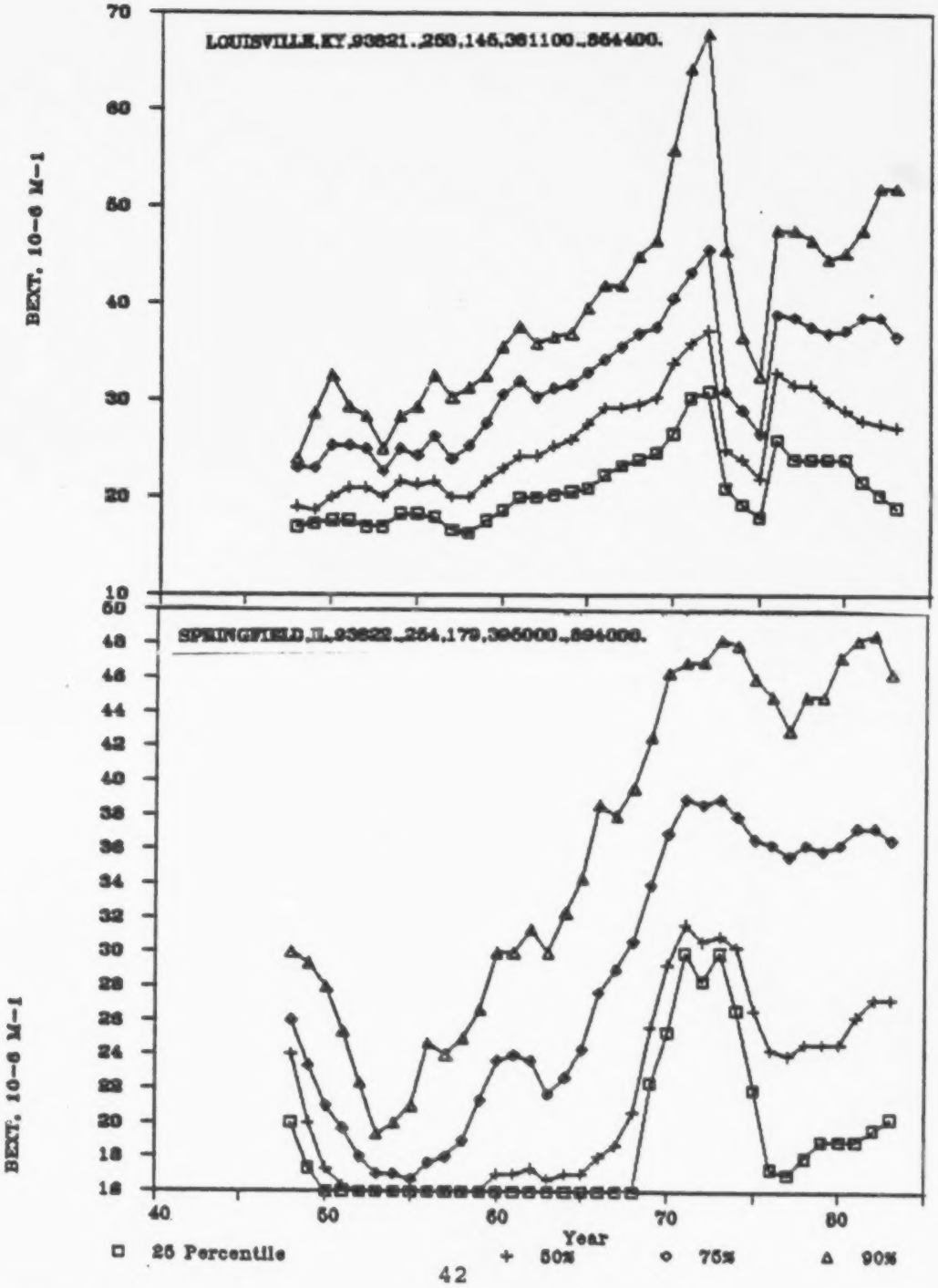
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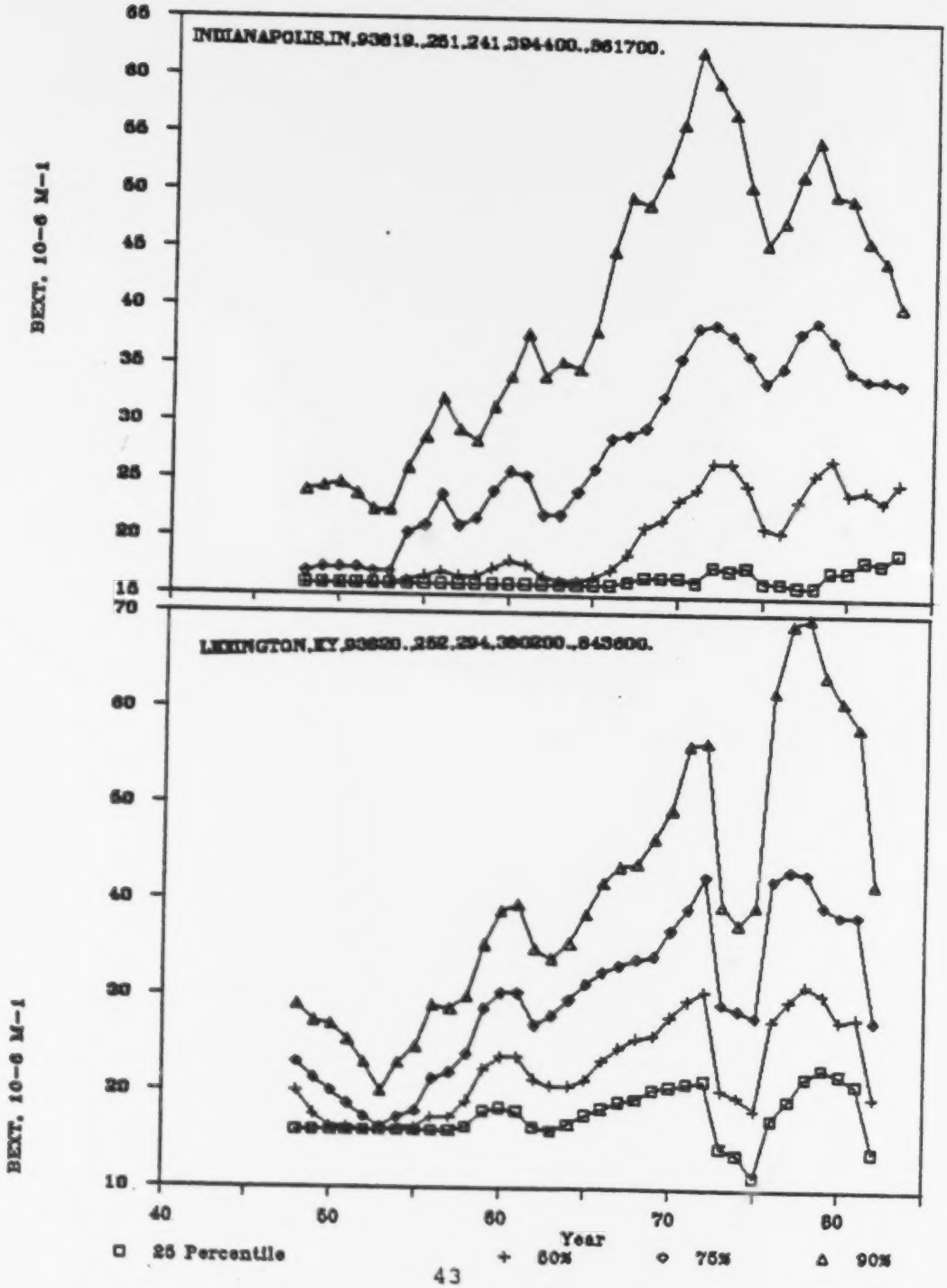
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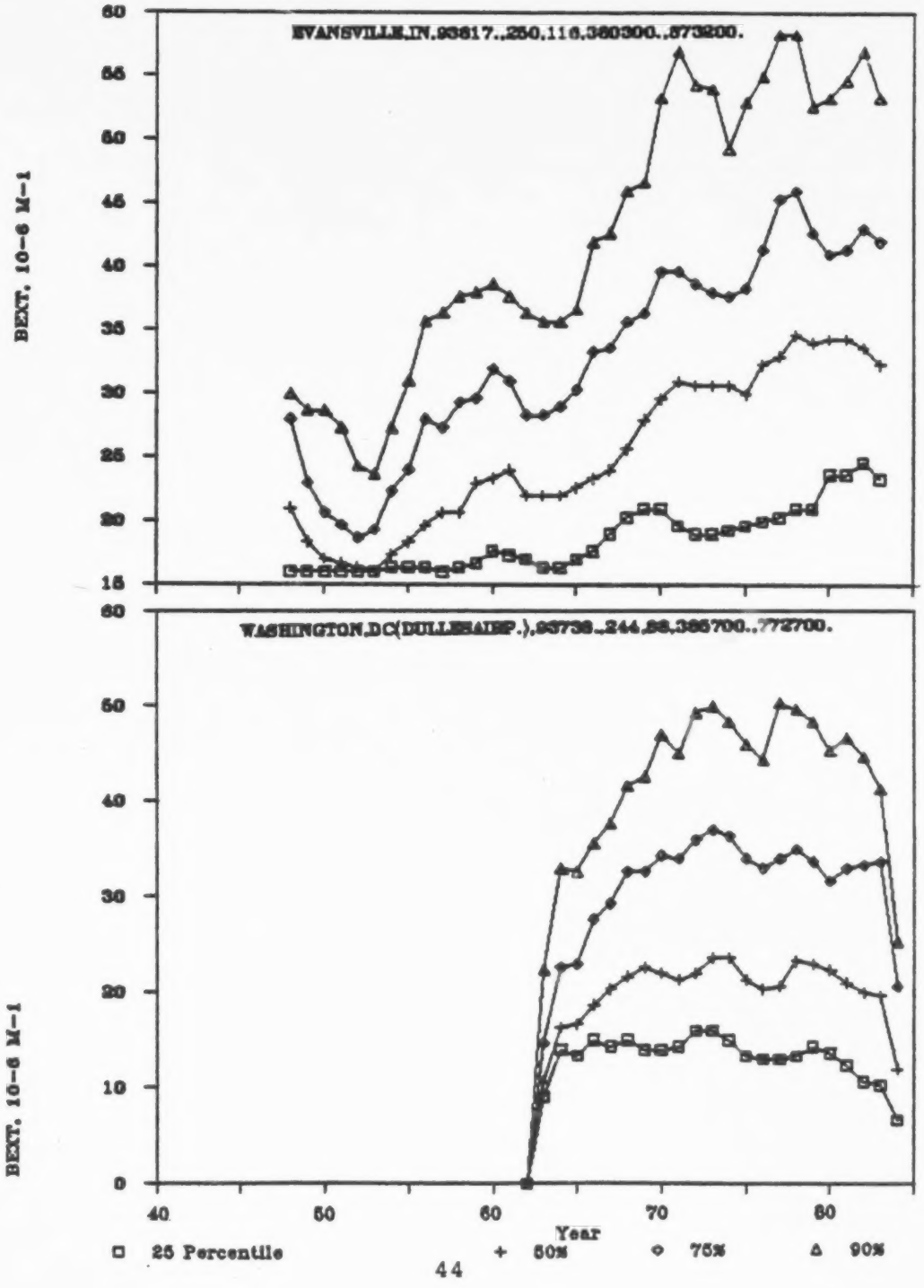
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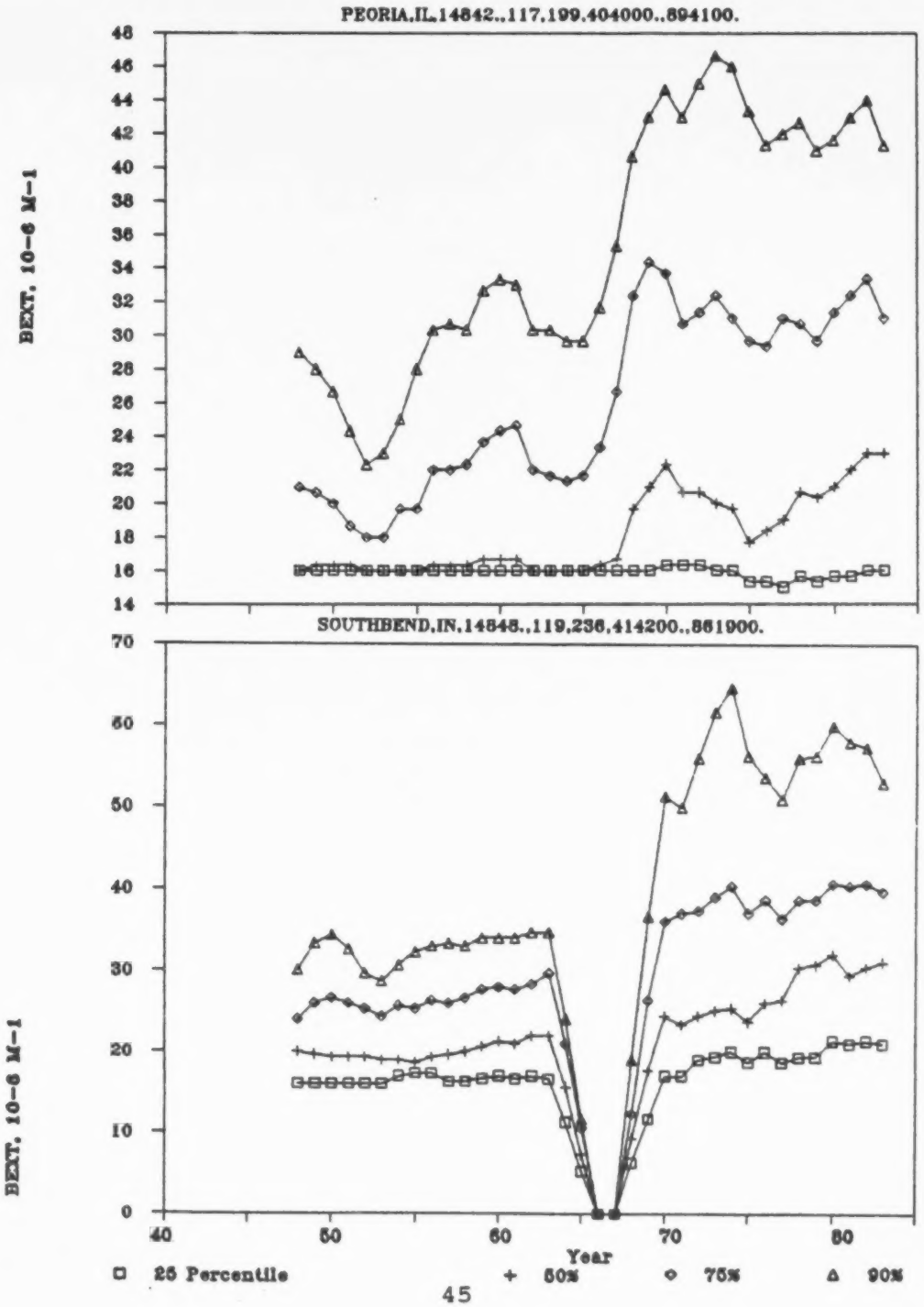
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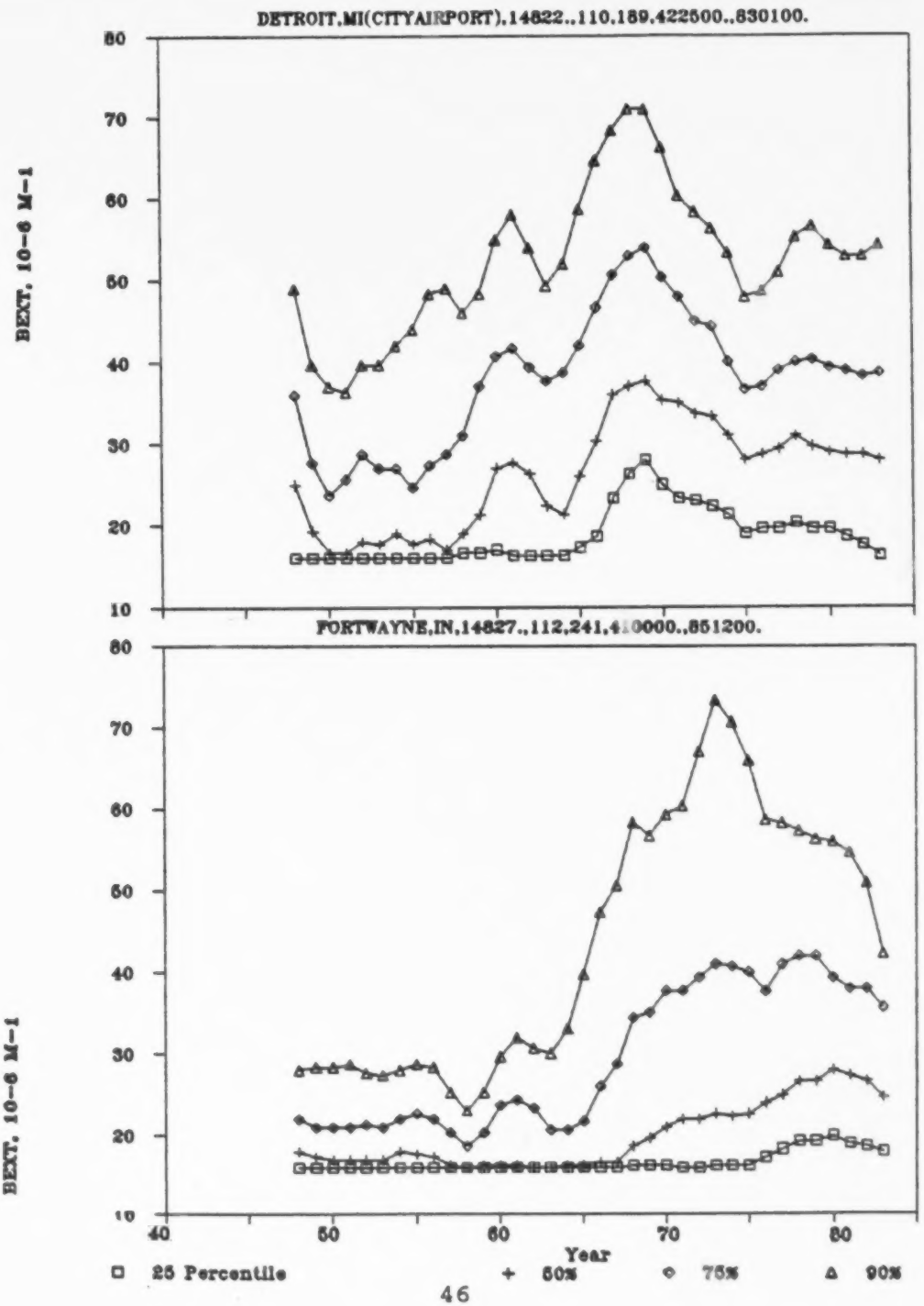
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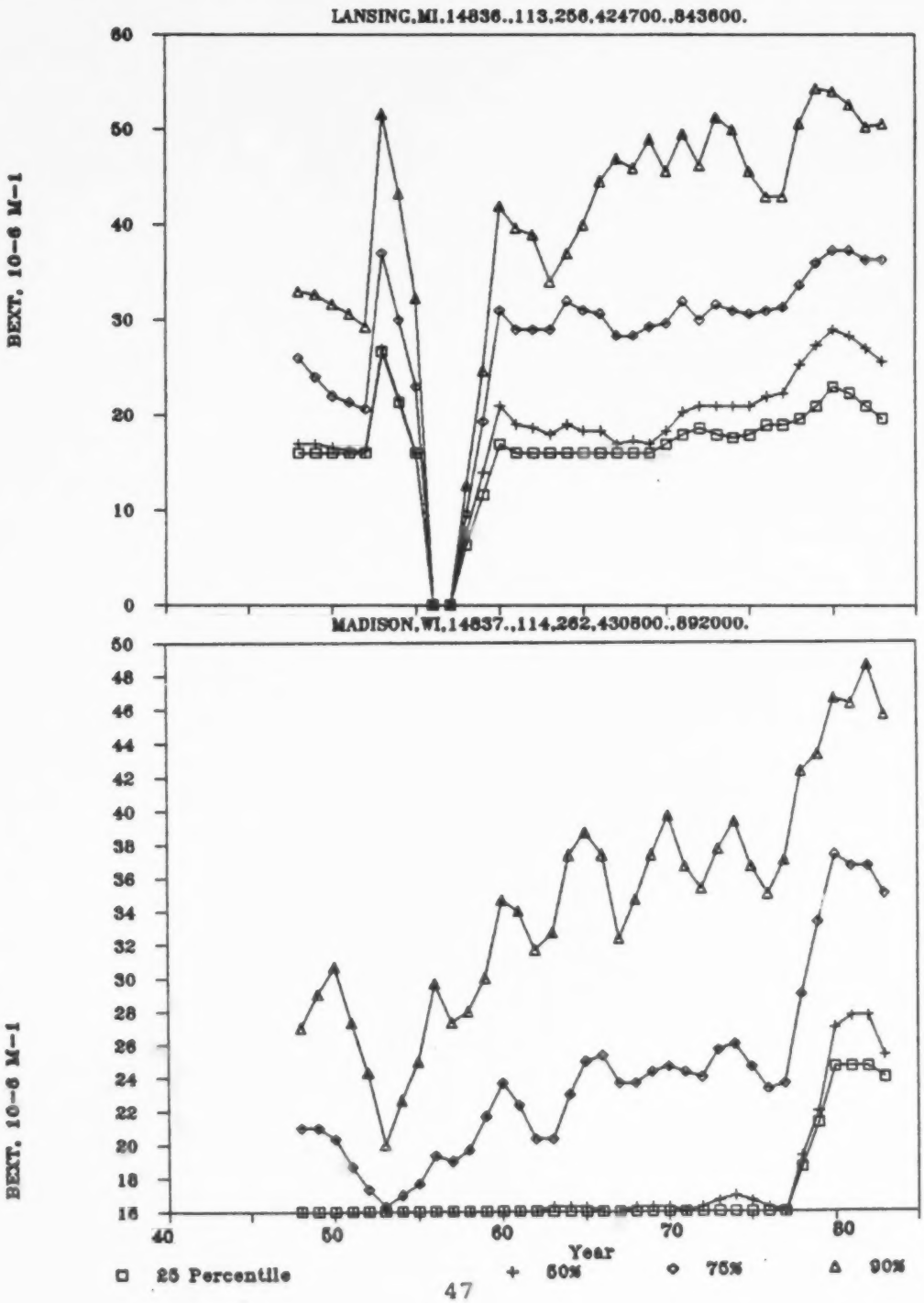
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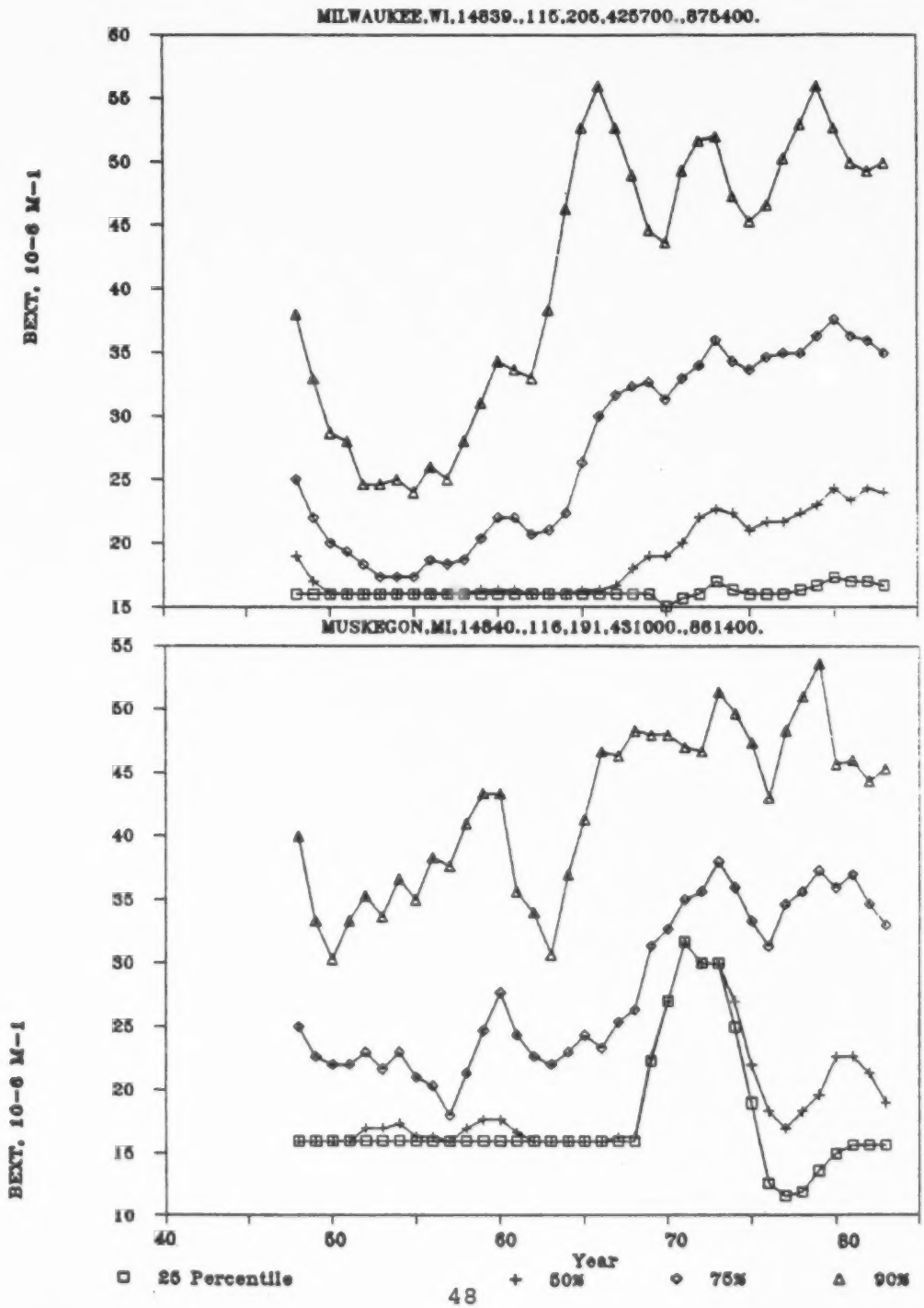
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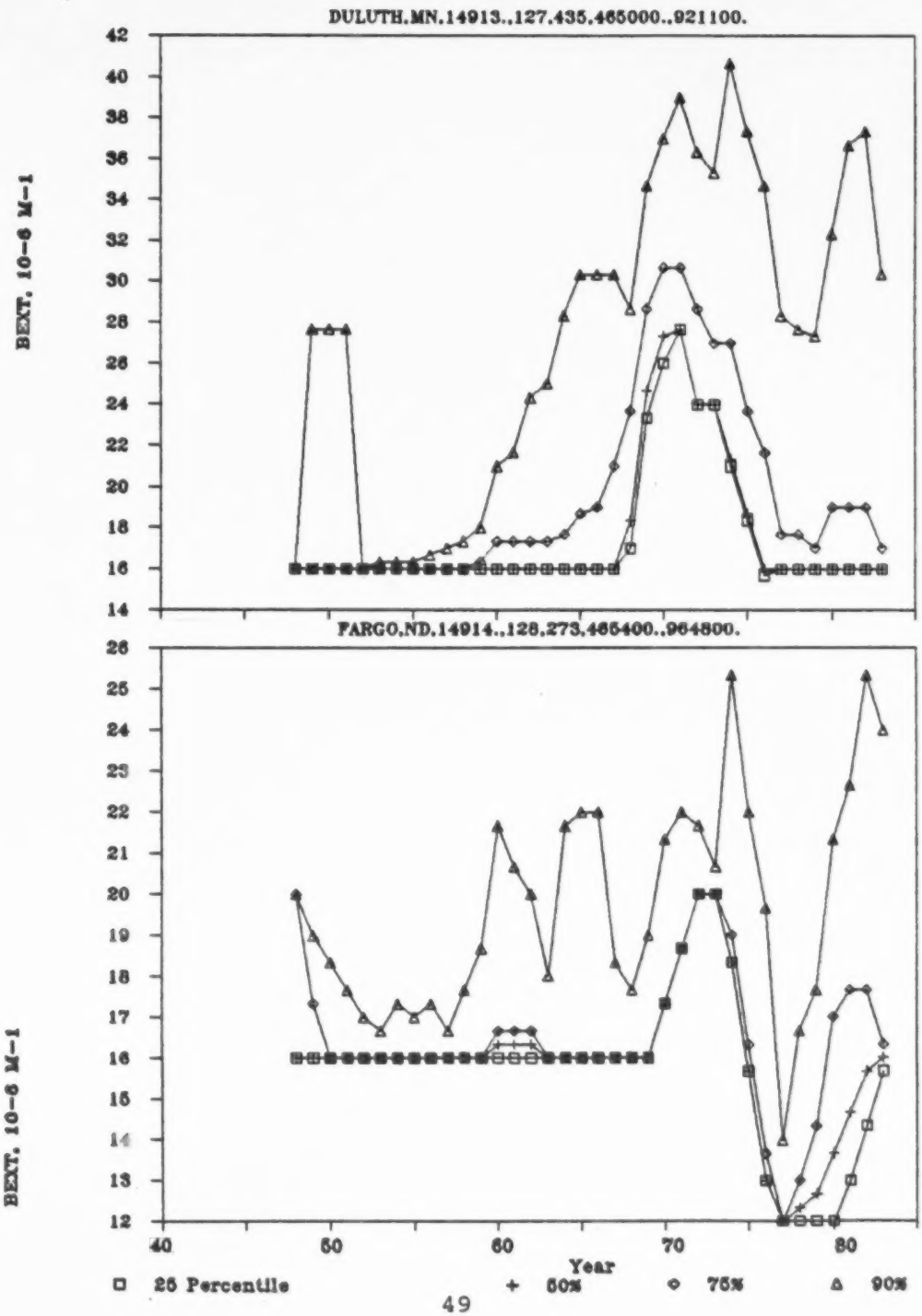
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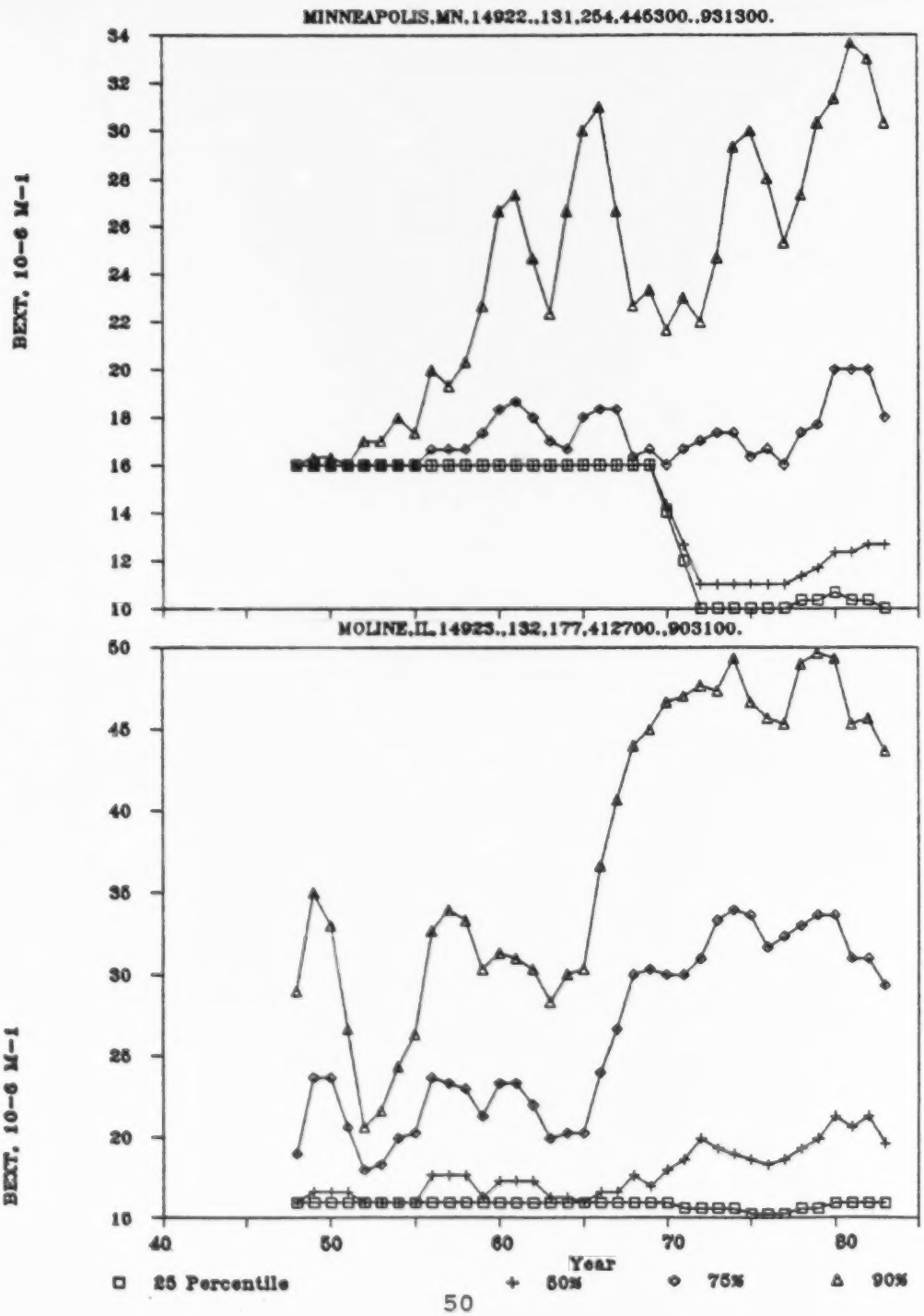
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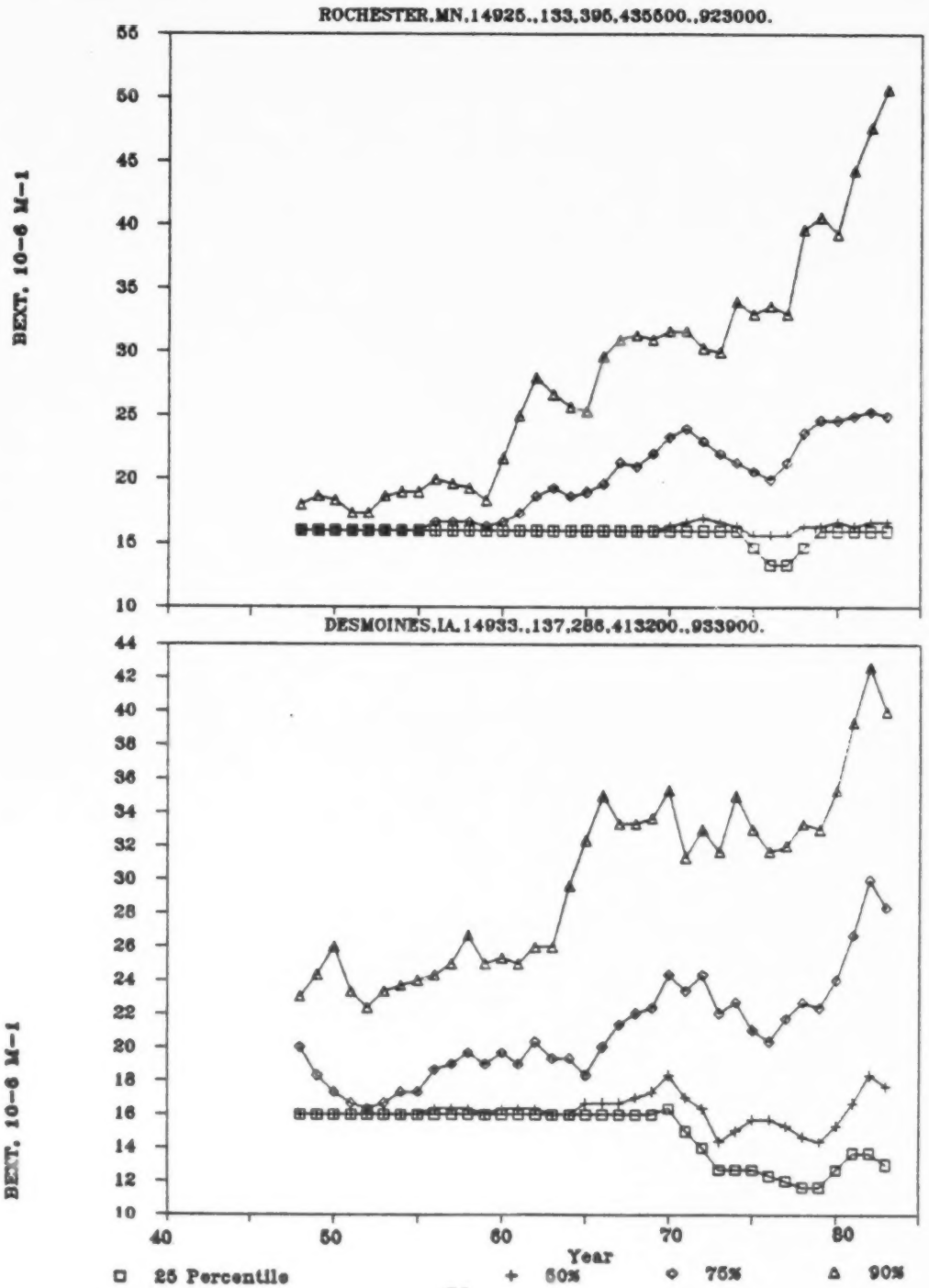
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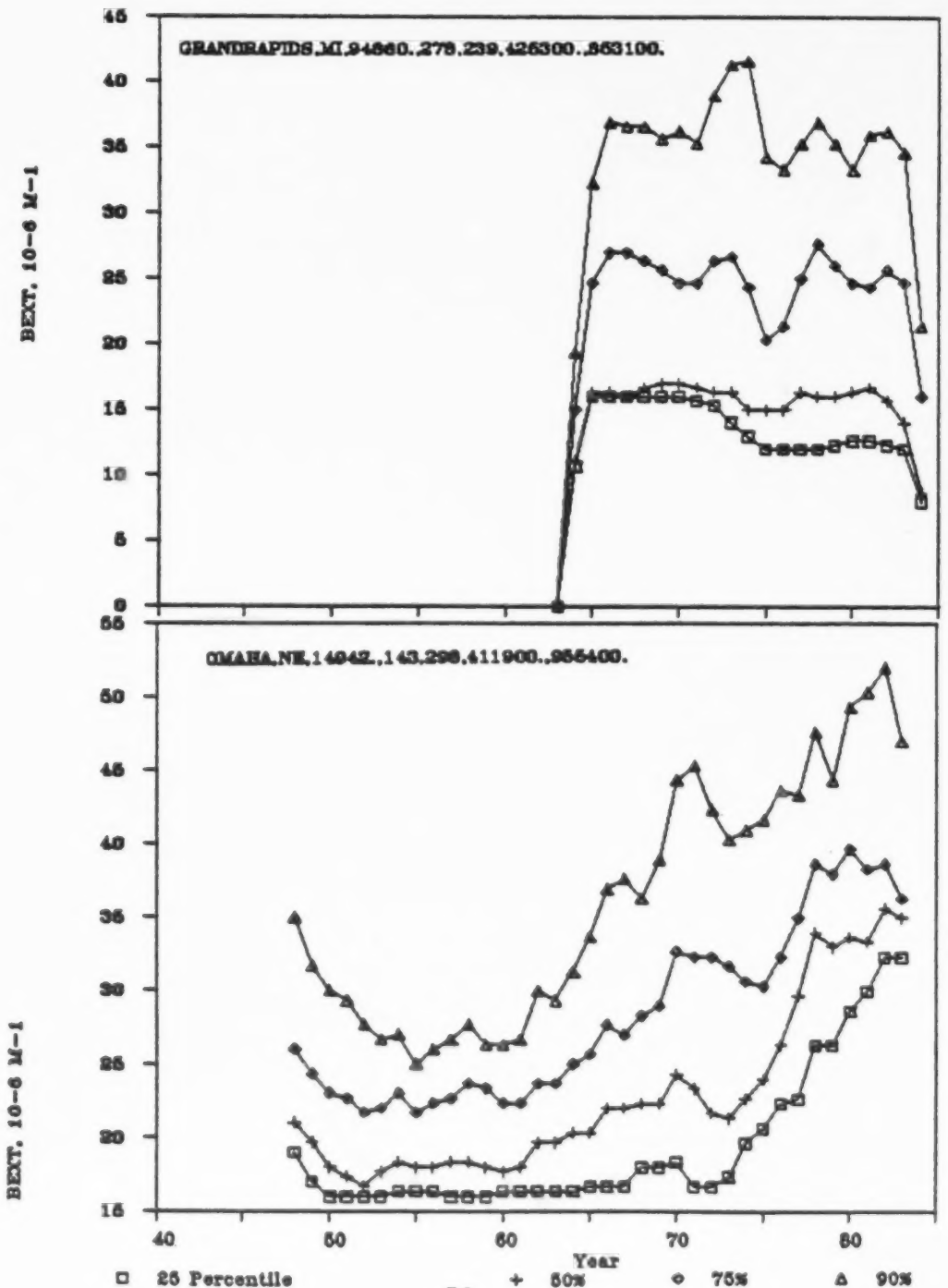
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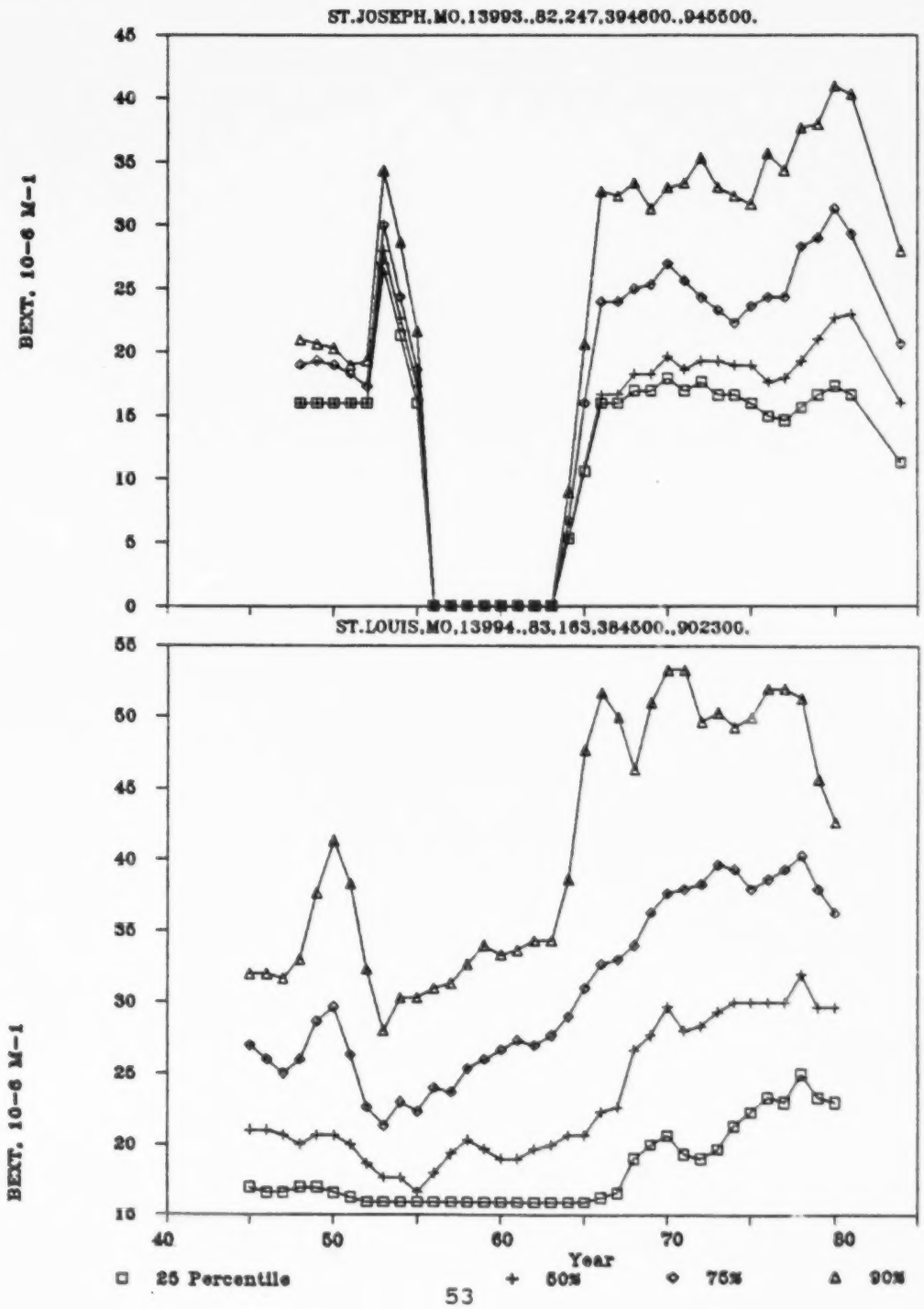
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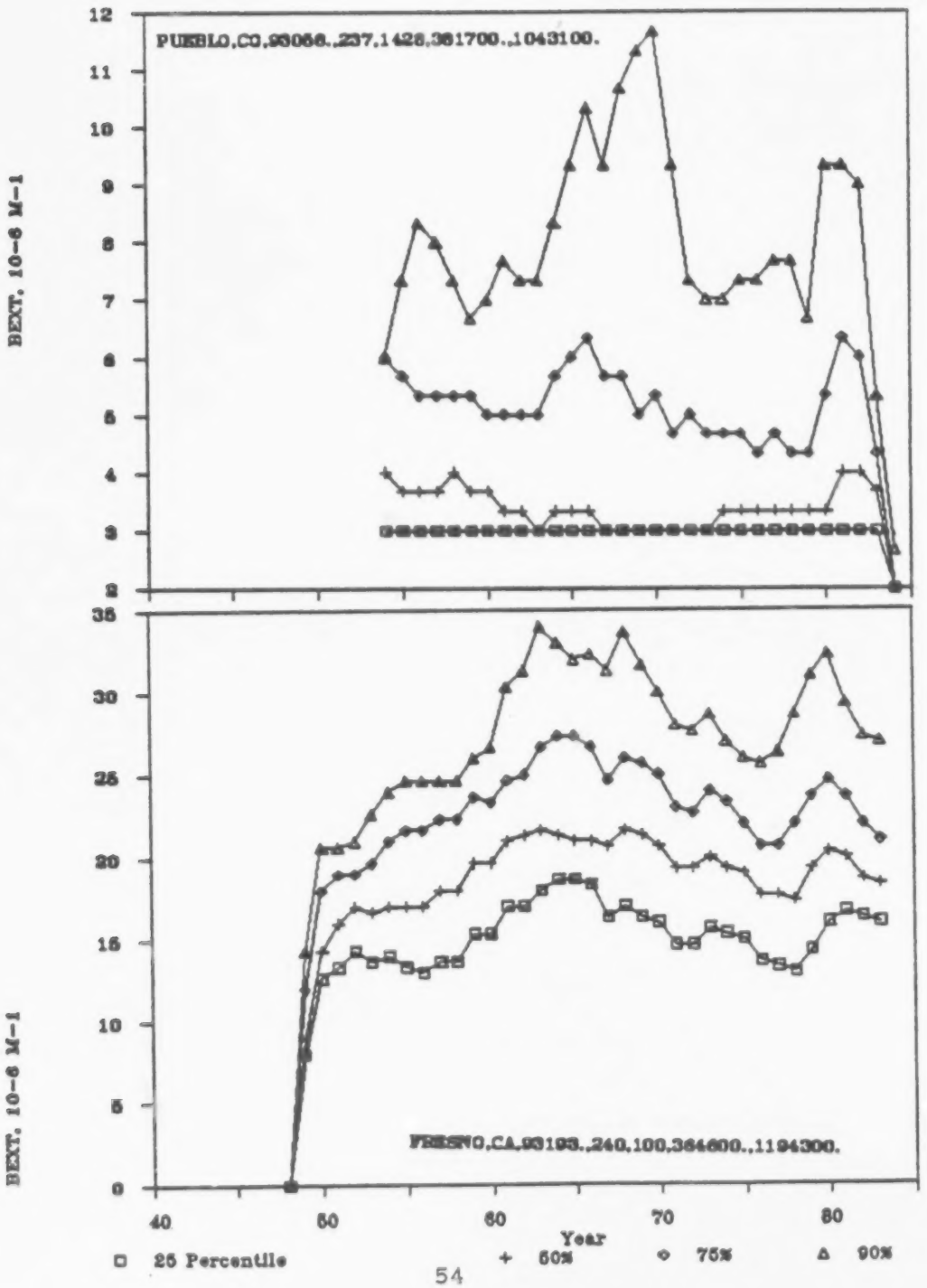
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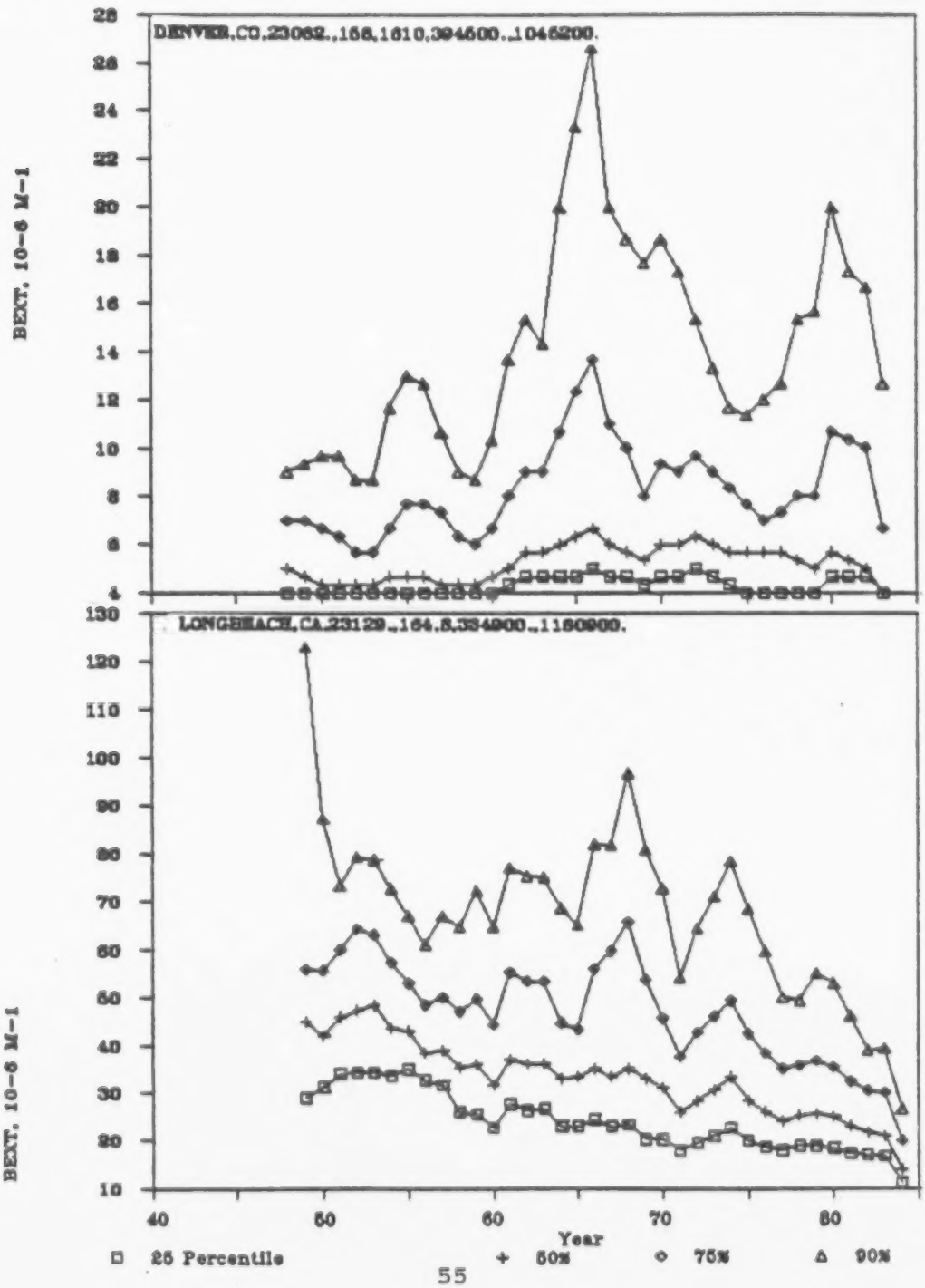
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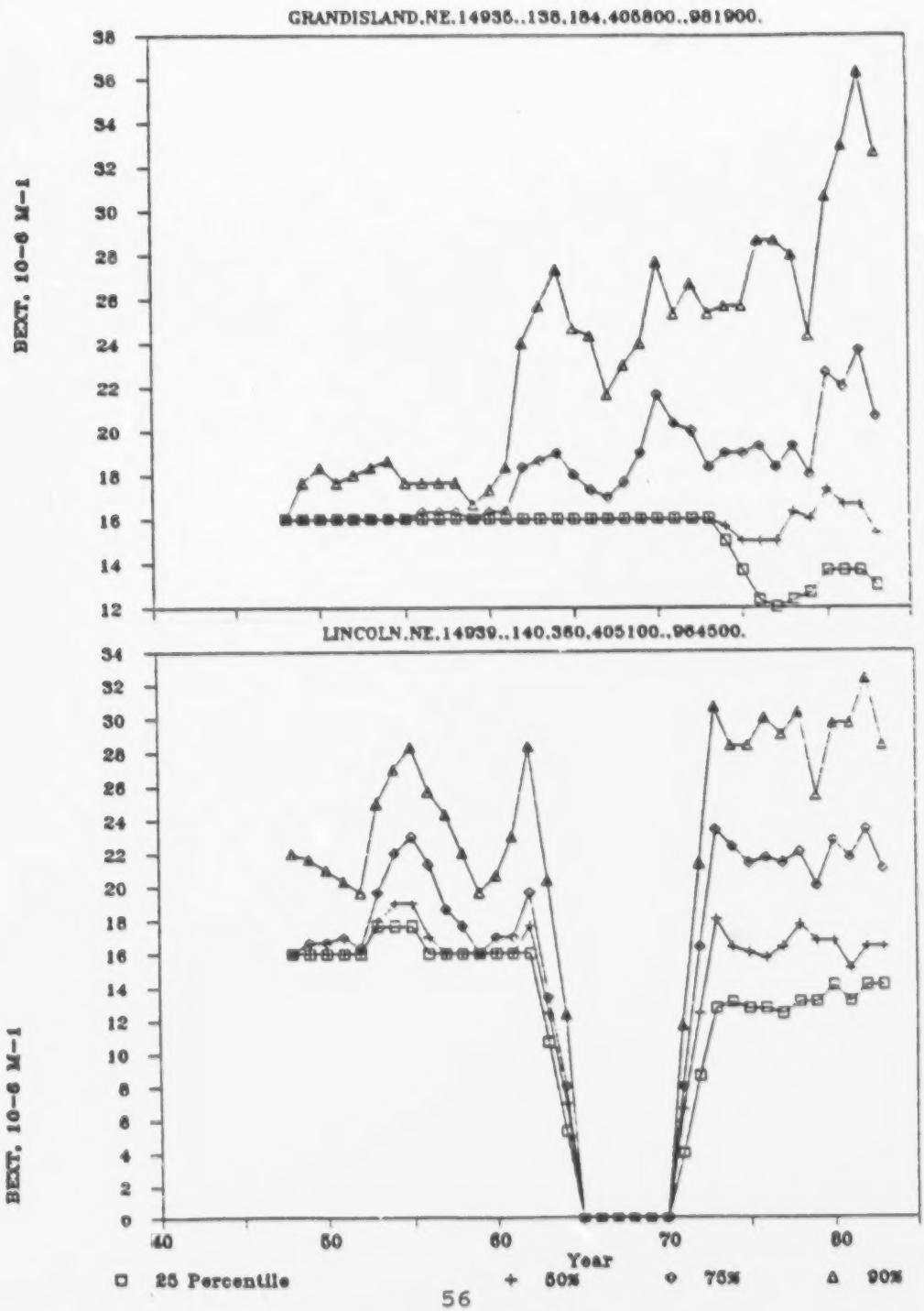
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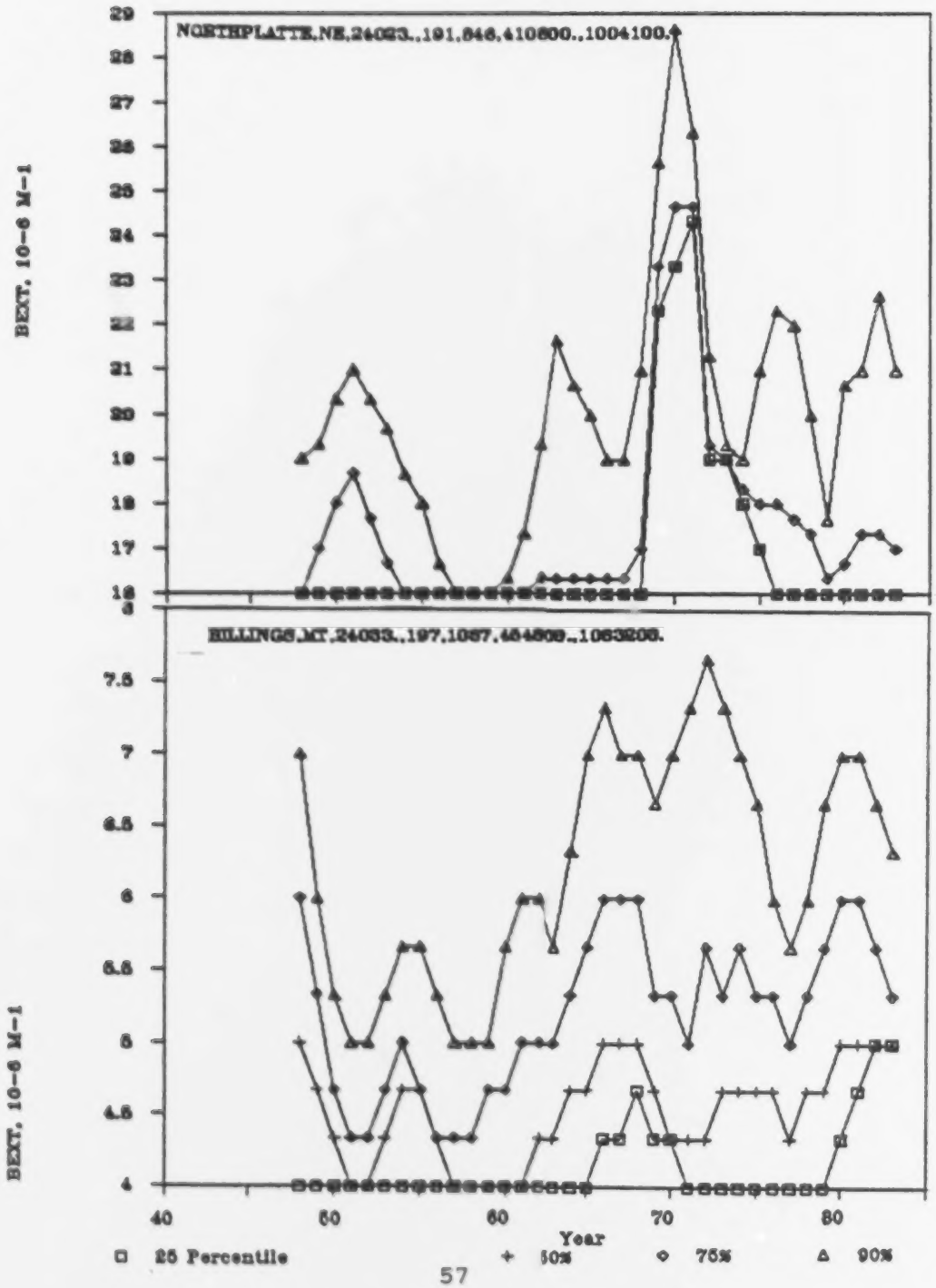
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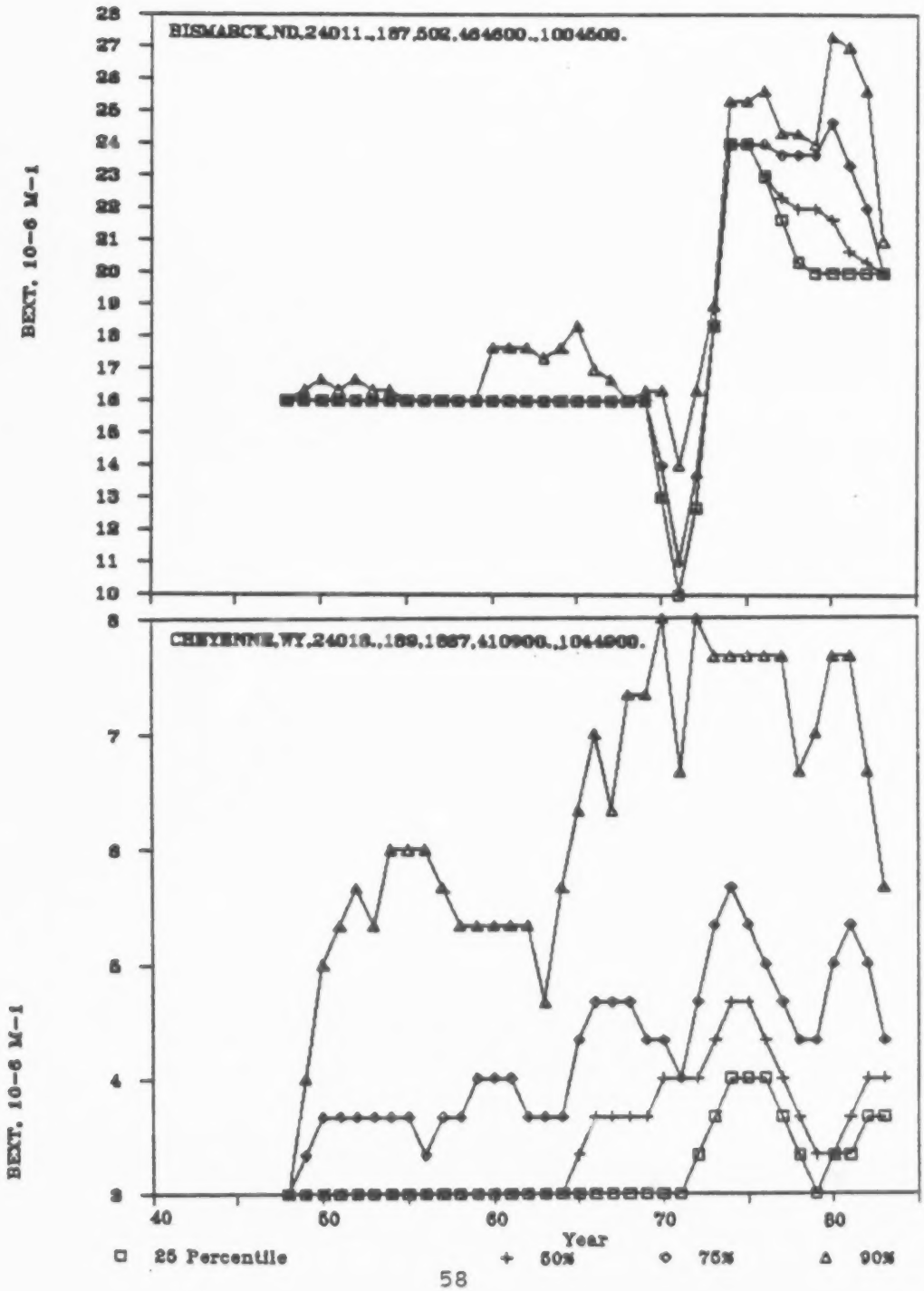
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CHEYENNE,WY,24018.,189,1887,410900.,1044900.
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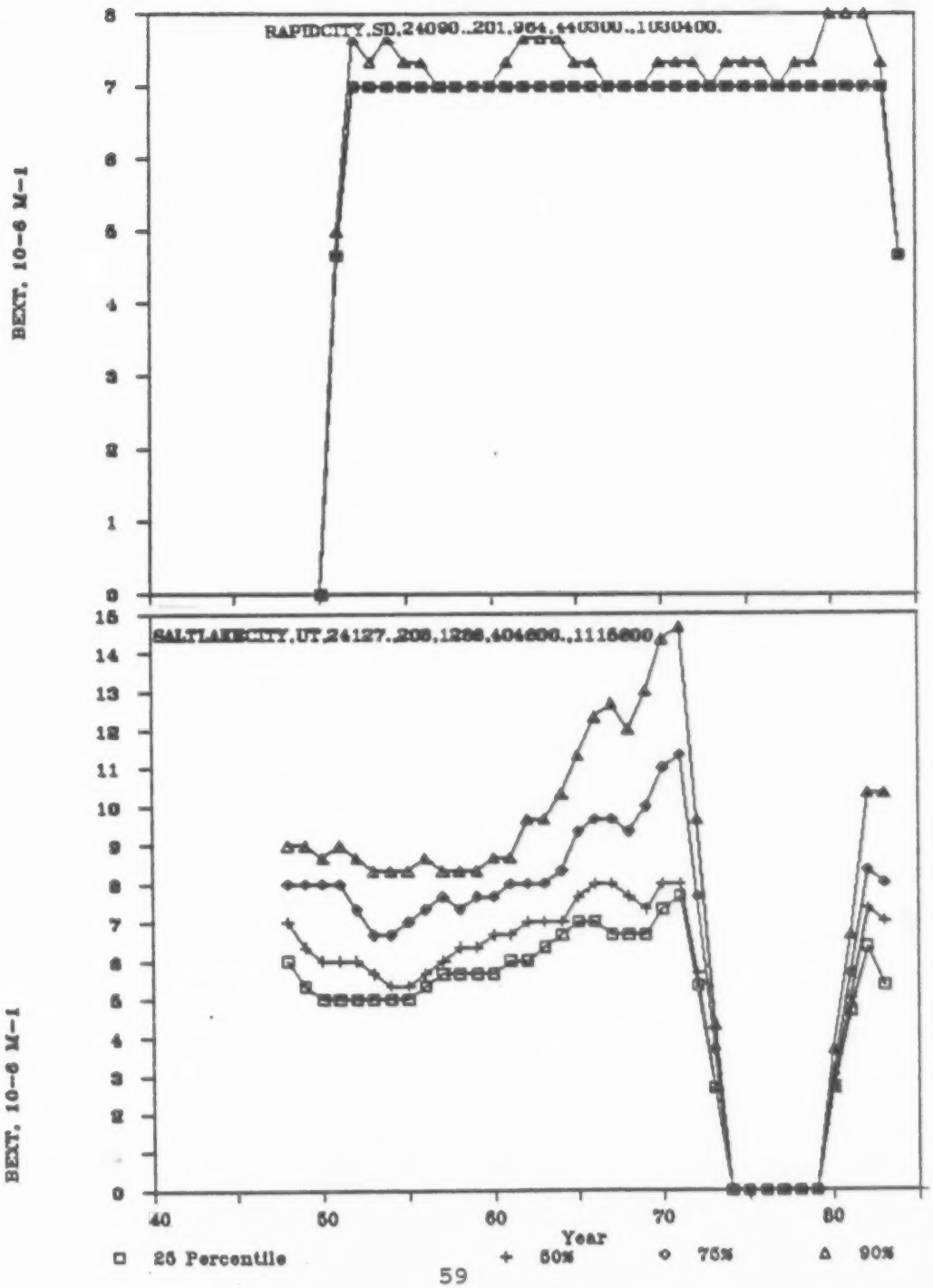
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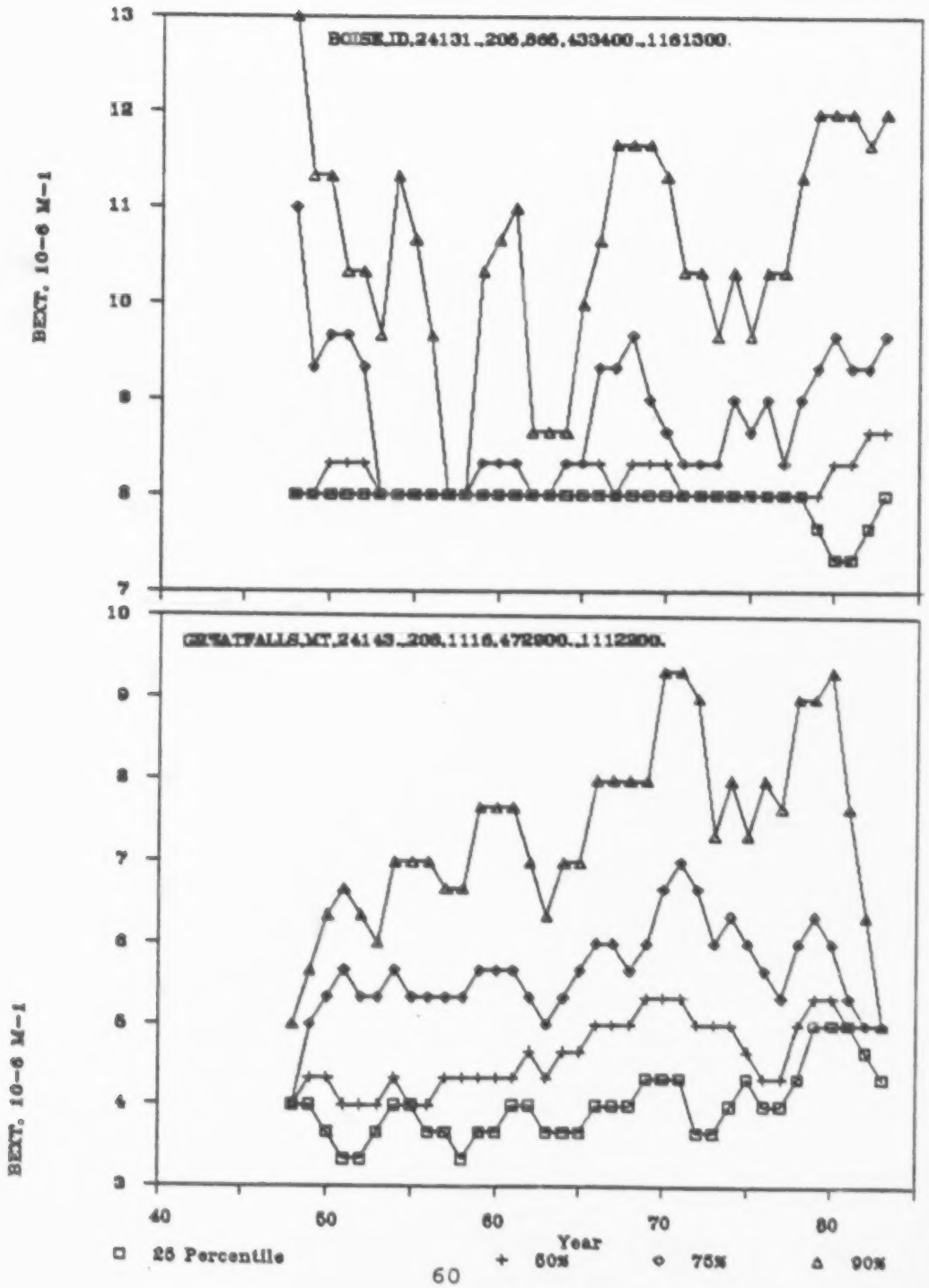
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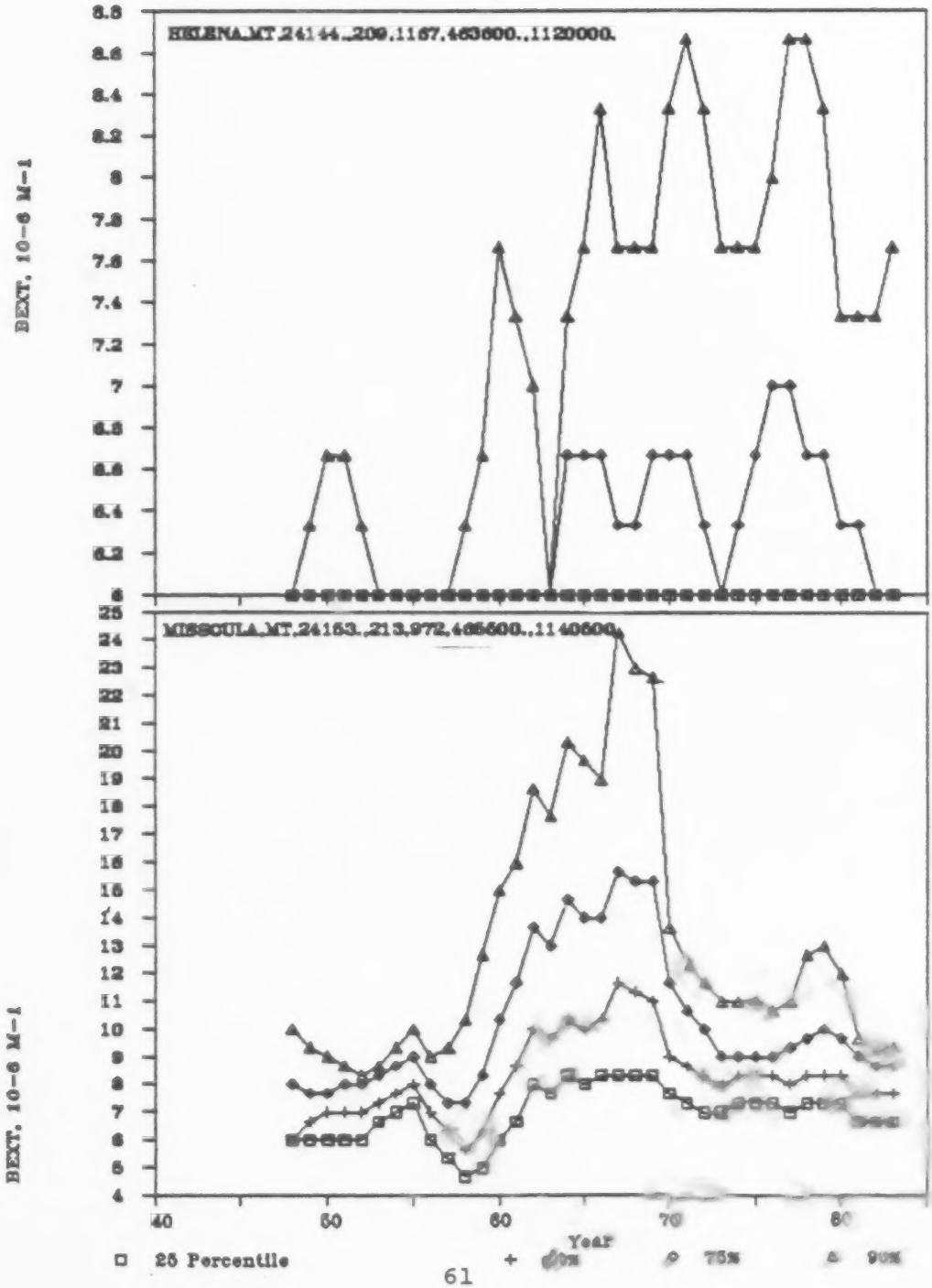
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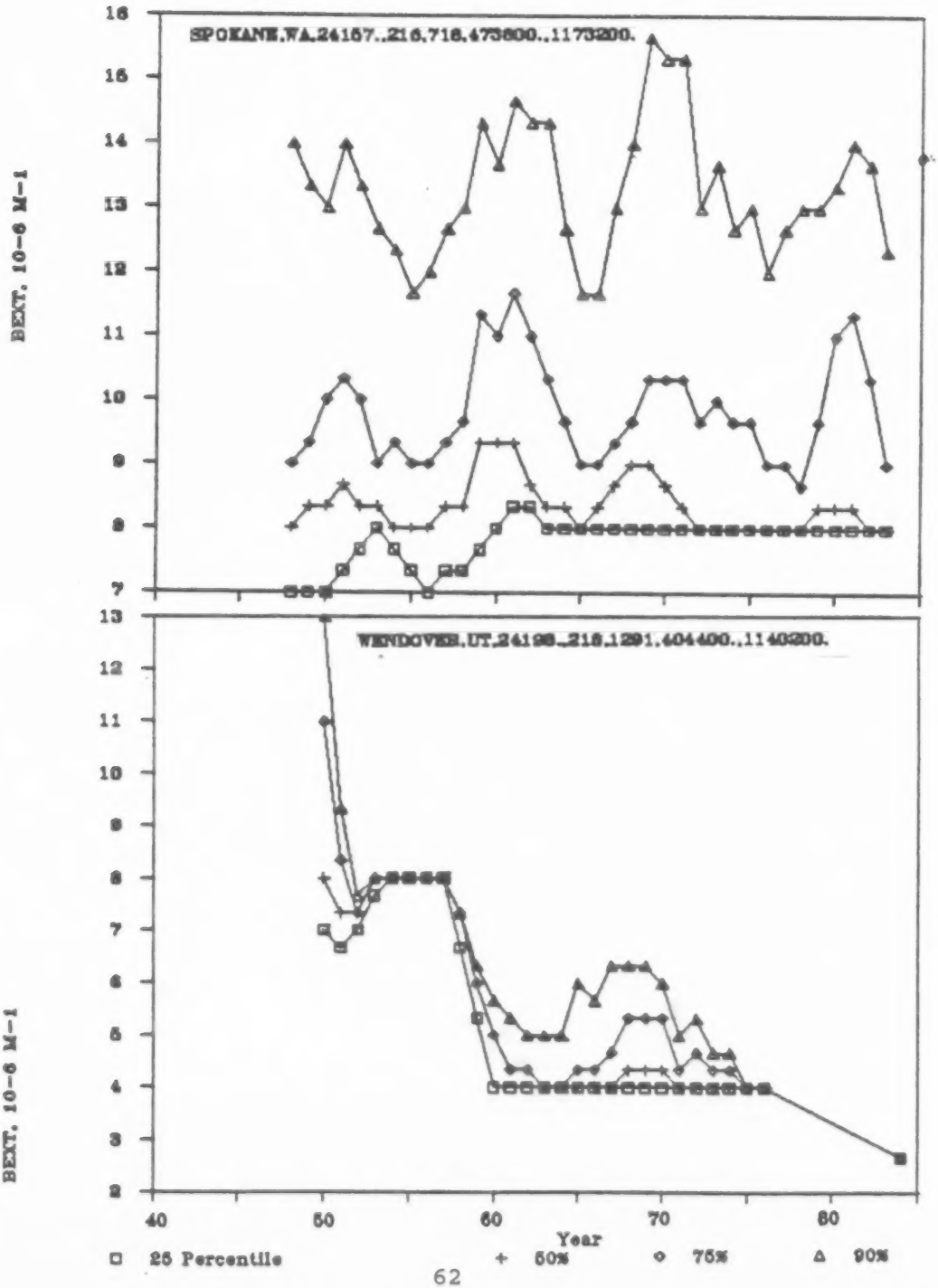
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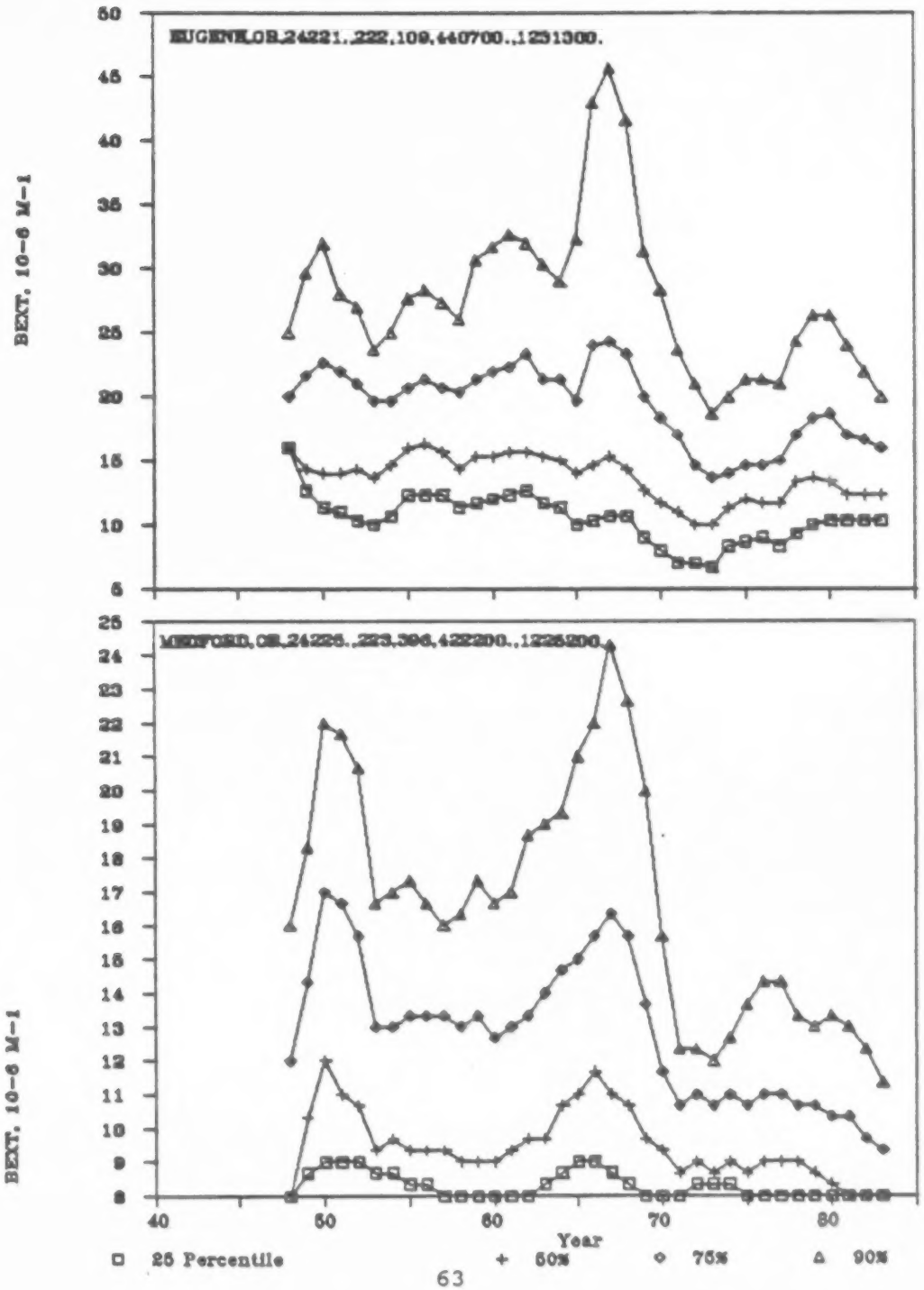
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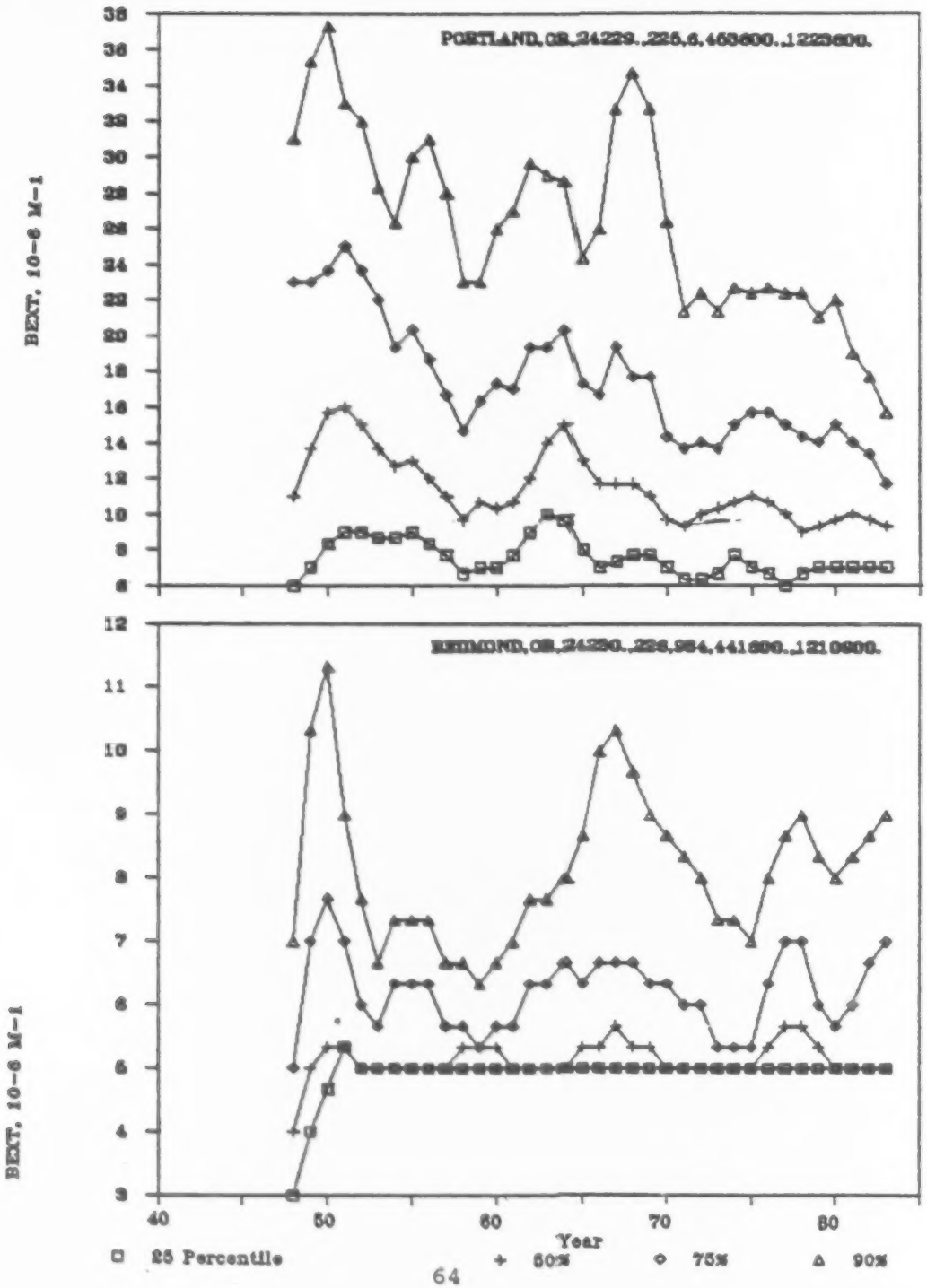
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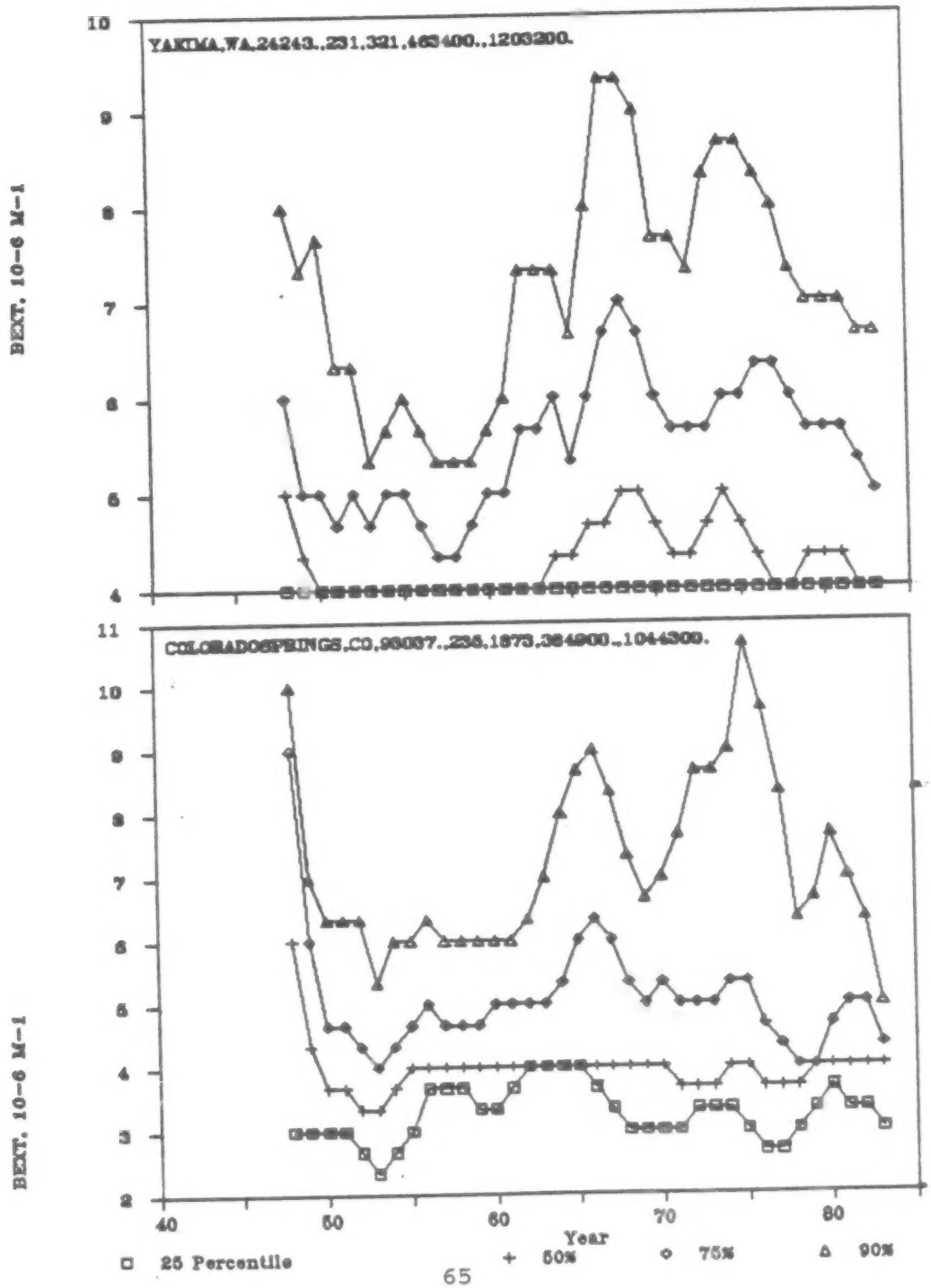
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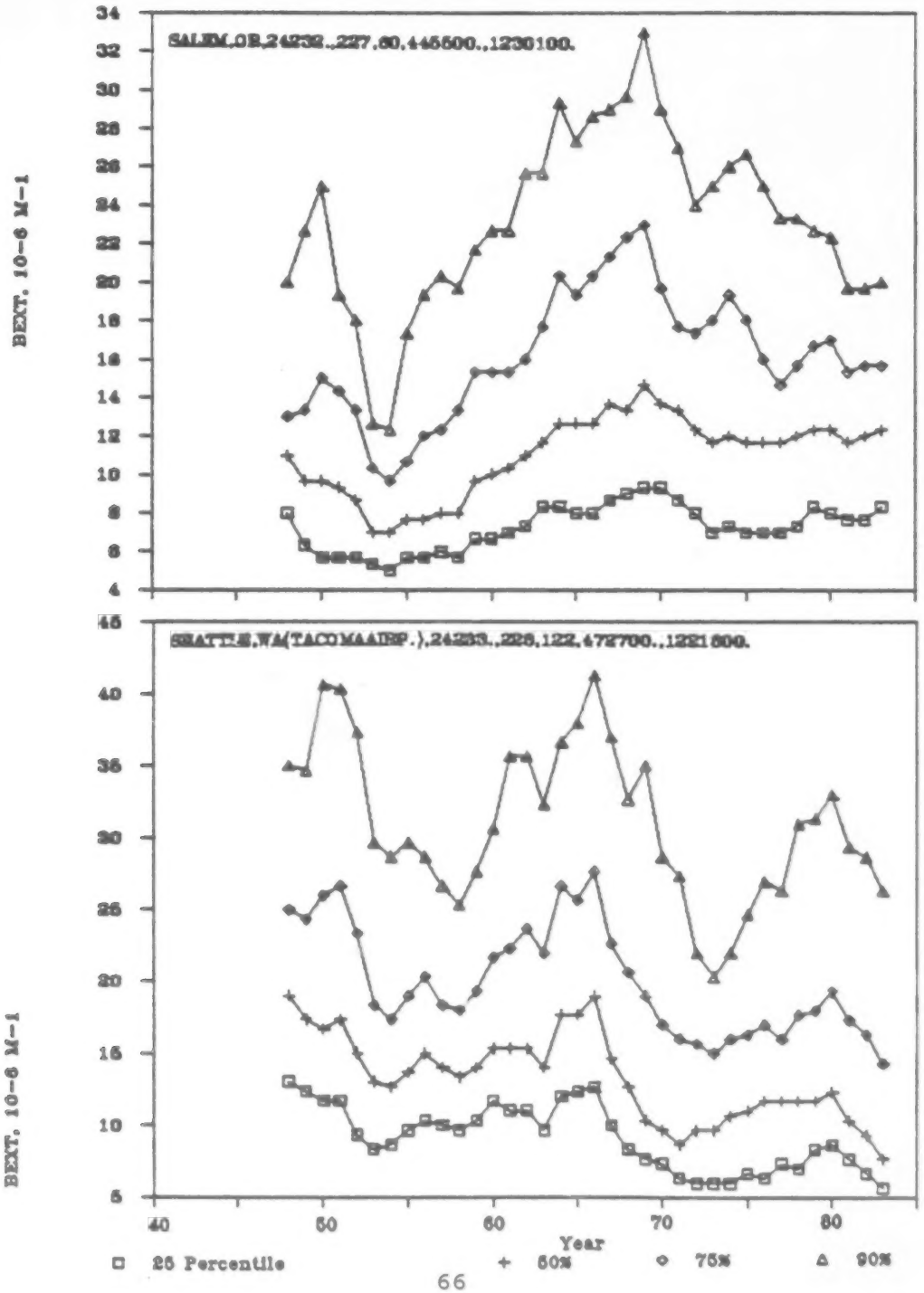
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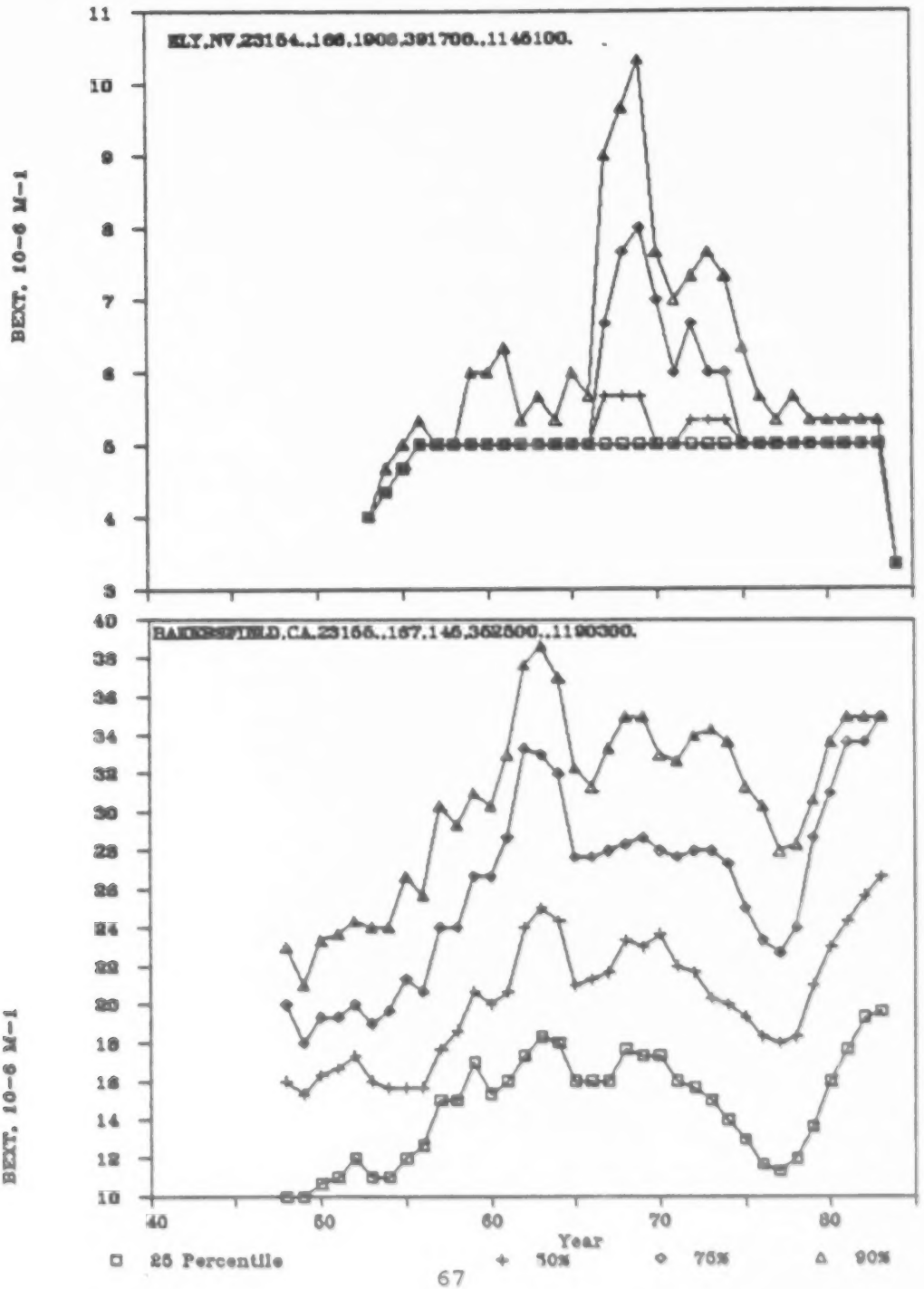
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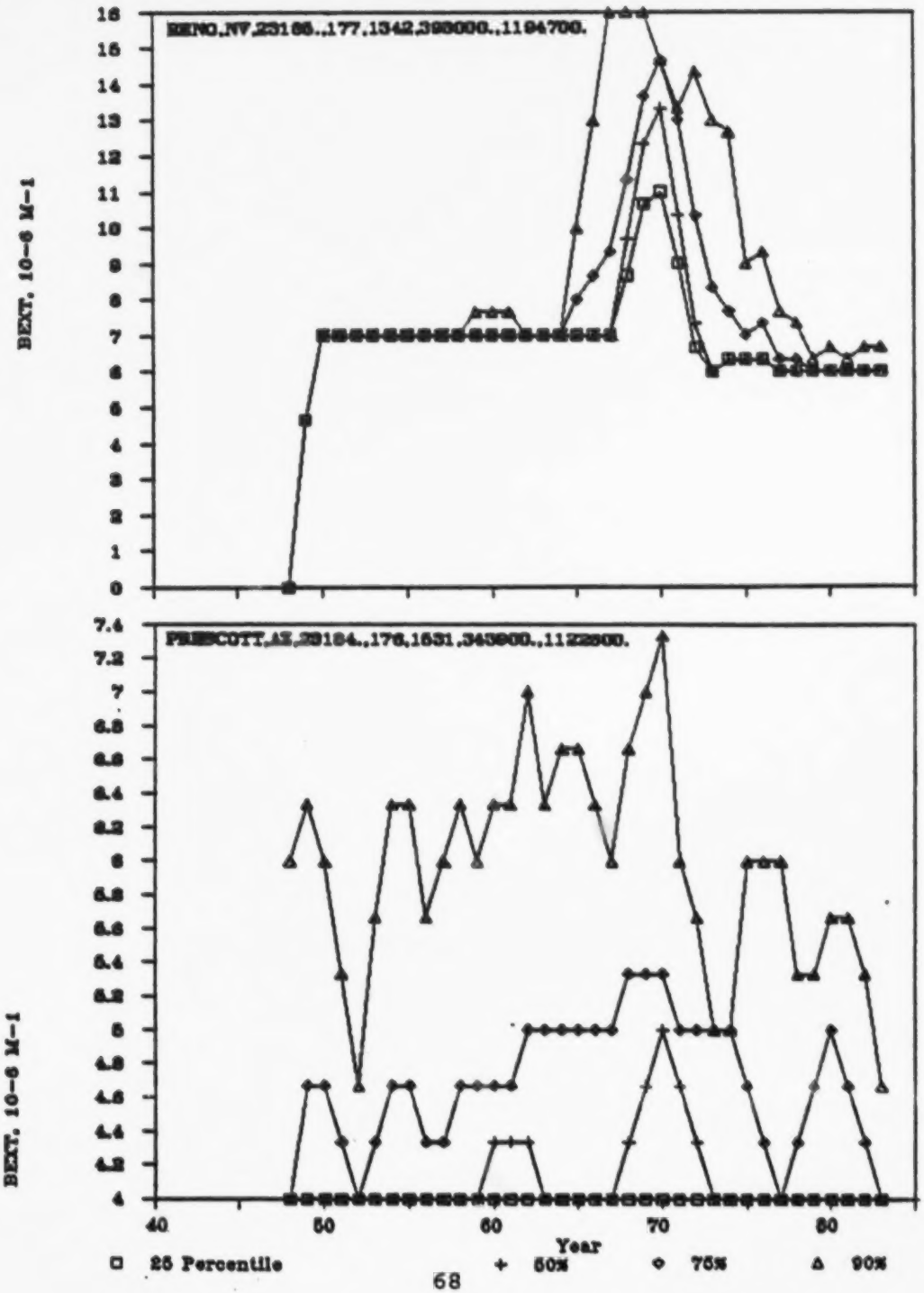
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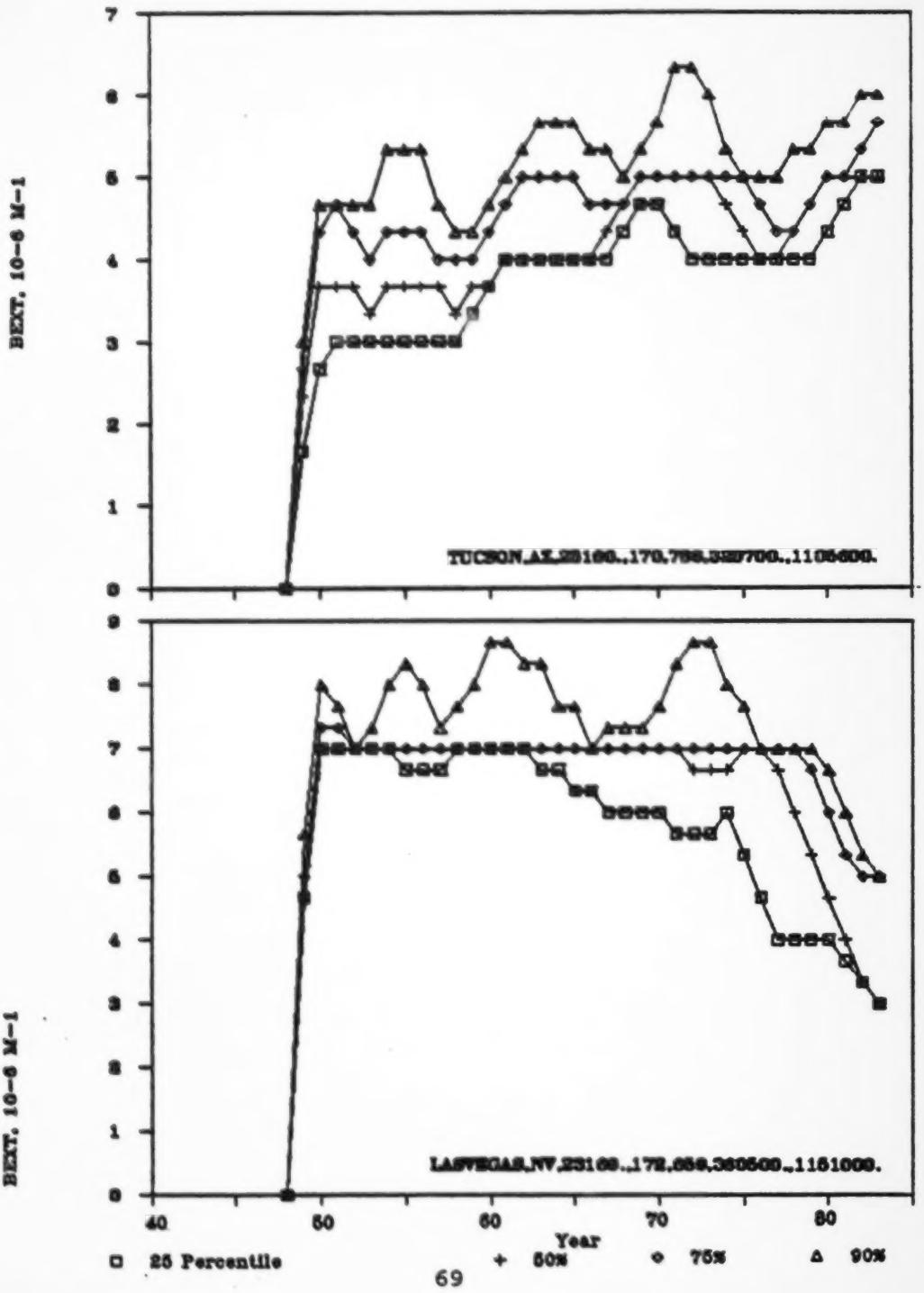
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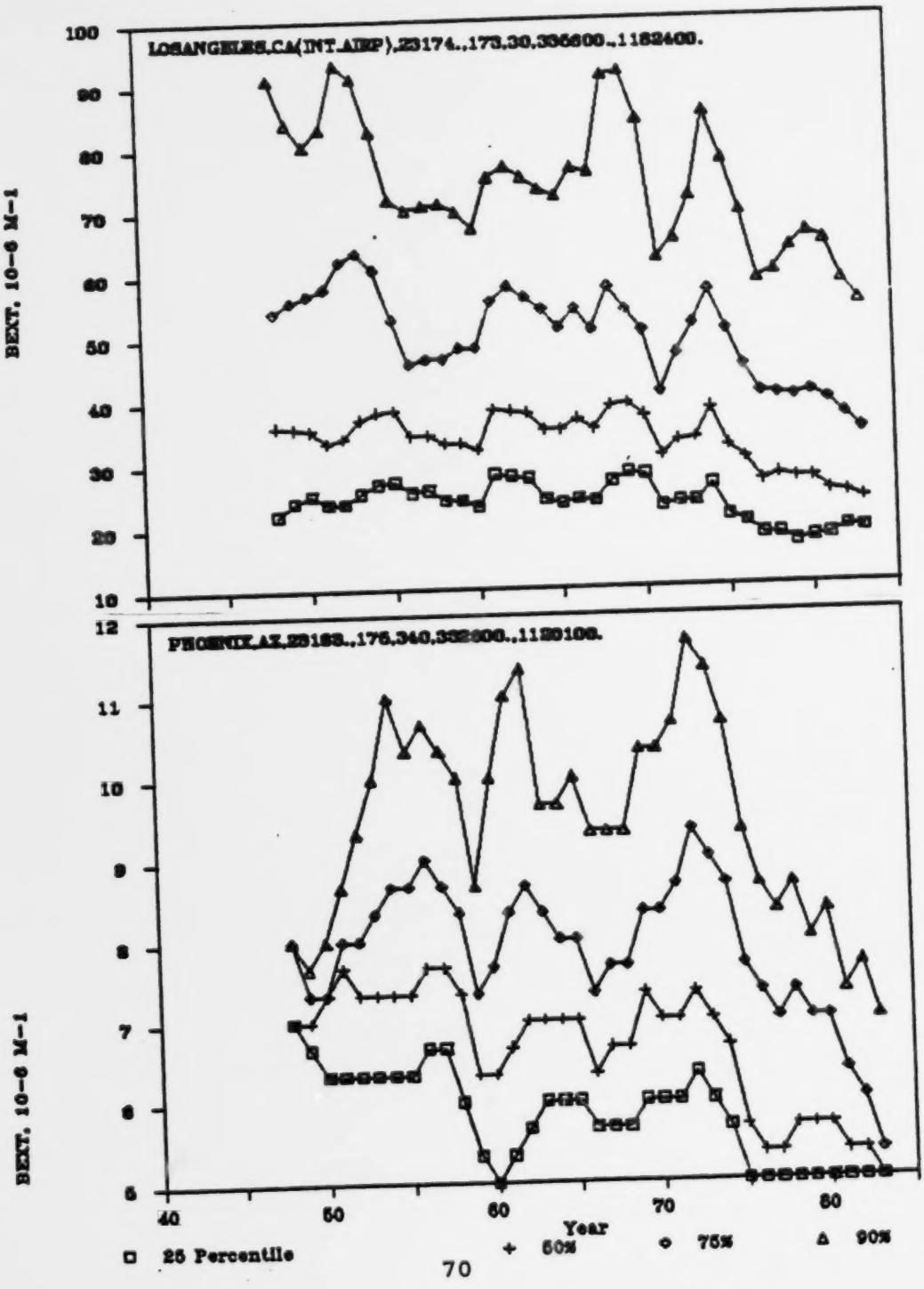
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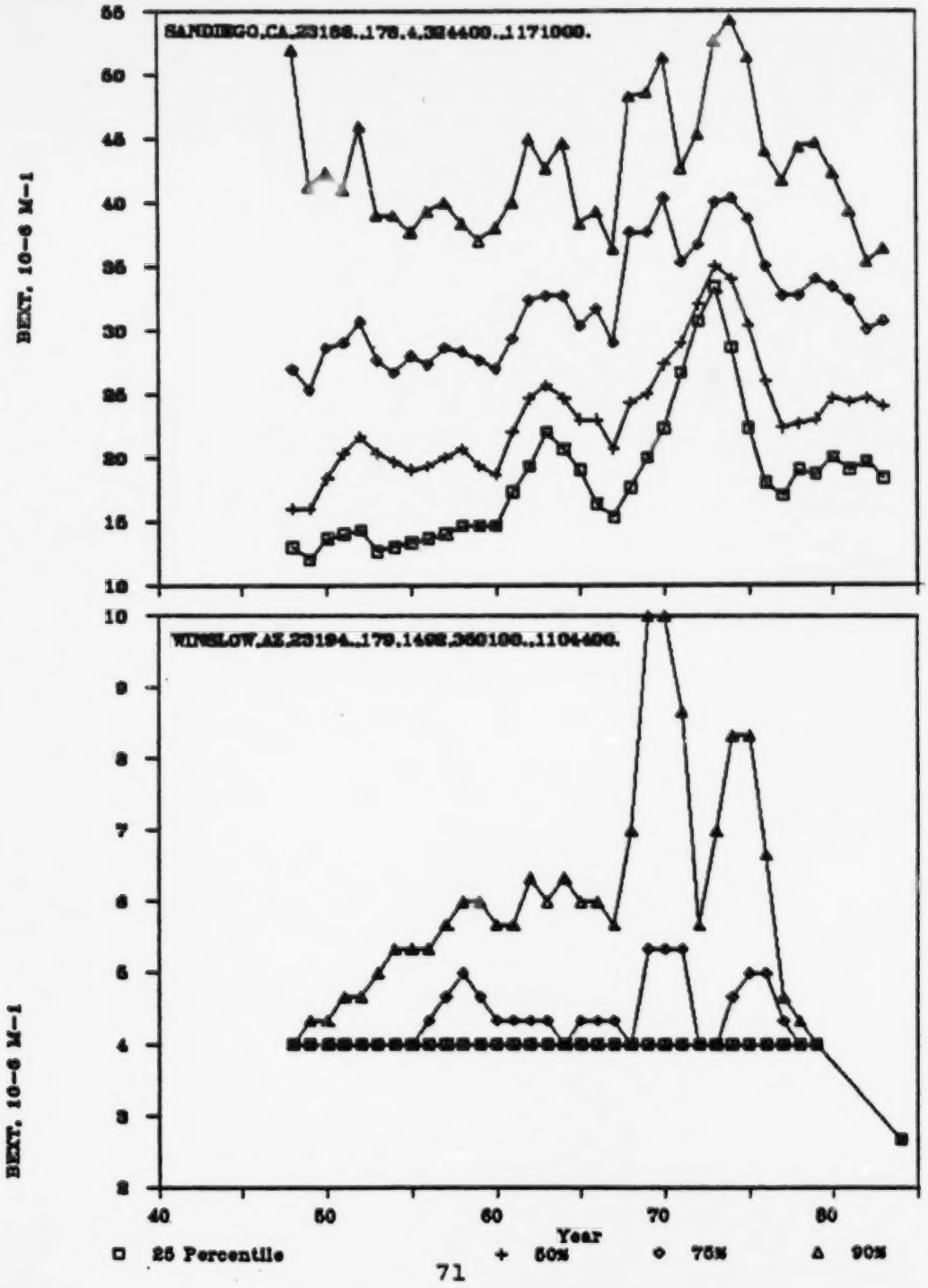
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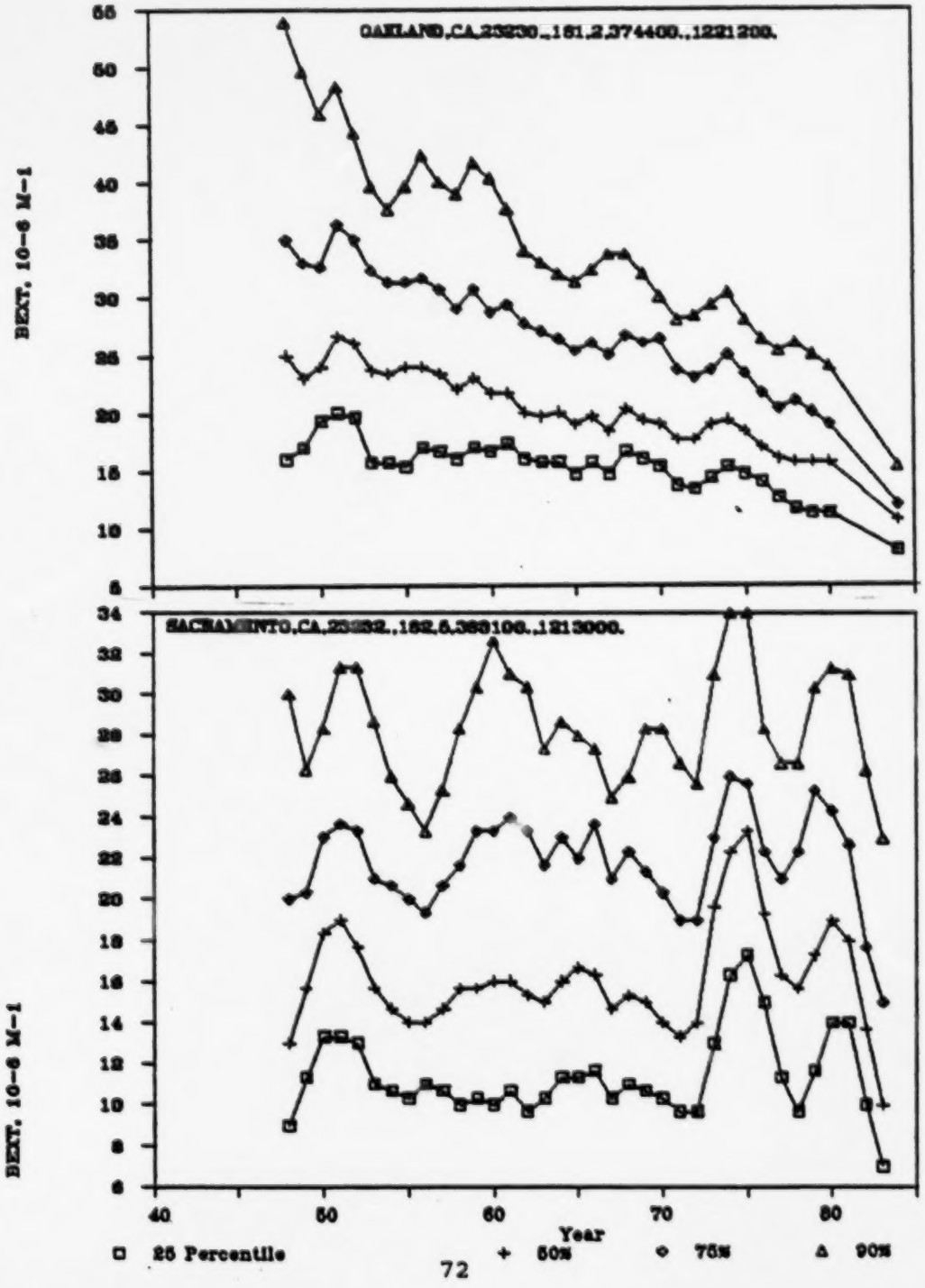
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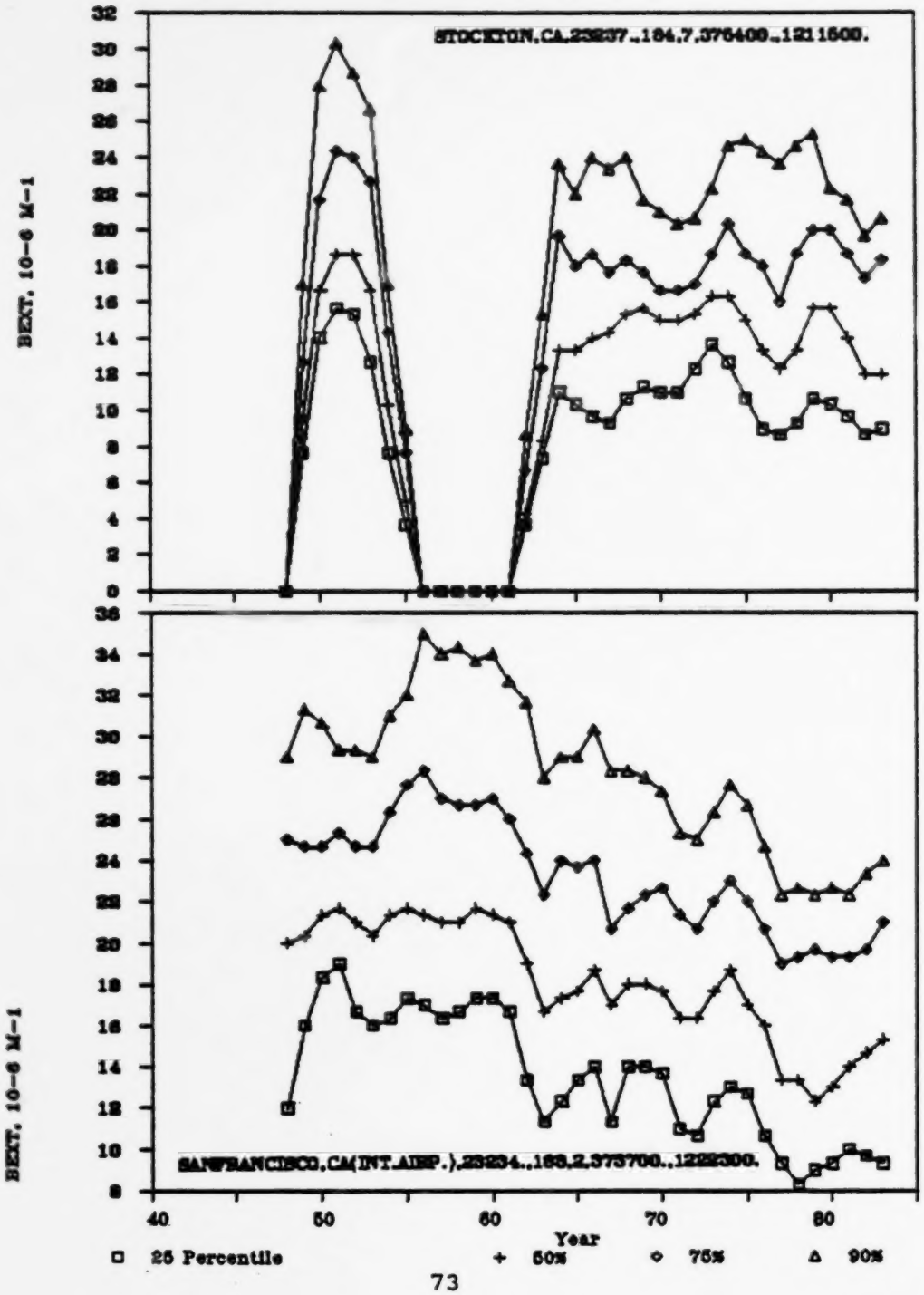
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